

AUTOMAATIOPÄIVÄT 2025 AUTOMATION DAYS 2025

25.-26.3.2025, Hotelli Tornii, Tampere

Automaatiopäivät 2025 Automation Days 2025

Extended Abstracts

ISBN: 13 978-952-5183-66-5

Edited by

David Hästbacka and Seppo Sierla

© 2025 Suomen Automaatioseura ry (SAS) – Finnish Society of Automation (FSA)
ISSN: 1455-6502

Asemapäällikönkatu 12 B, 00520 Helsinki, Finland, www.automaatioseura.fi



SUOMEN AUTOMAATIOSEURA RY
FINNISH SOCIETY OF AUTOMATION

Tapio Haapamäki*, Mika Nieminen and Reino Virrankoski

Utilization of Multirotor Drones, Small Satellites and Other Sensor Systems in Airbase Protection

Abstract: In addition to traditional sources of information, new and disruptive technologies equipped with several types of sensors produce a huge amount of real-time information. Observed physical space consists of five components: air, sea, ground, space and electromagnetic spectrum. A real-time presentation of the situation in the observed space is called the common operational picture (COP), and it forms the basis of the decision making and actions. A huge amount of real-time measurements and their continuous data flow requires automated data processing to compute, update and share the COP as real-time as possible. This article discusses about the utilization of multirotor drones, small satellites and other sensor systems in airbase protection. Recent MULTICO-project is used as a case study, and conclusions are presented based on the project results, and further observations during and after the project.

Keywords: sensors, drones, small satellites, situational awareness

***Corresponding Author: Tapio Haapamäki:** Air Systems Depot, E-mail: tapio.haapamaki@mil.fi

Mika Nieminen: National Defence University, E-mail: mika.nieminen@mil.fi

Reino Virrankoski: Aalto University, E-mail: reino.virrankoski@aalto.fi

1 Introduction

The rapid development of autonomous systems and sensors is changing the modern warfare. Traditional geographic battlefield has been extended to battlespace, which has the components of air, sea, ground, space and electromagnetic spectrum. These all must be taken into account in the common operational picture (COP). When the systems become more complex, there are increasing number of real-time observations. As a consequence, automated data processing is needed to compute, update and share the COP as real-time as possible. On the other hand, new and disruptive technologies are not operating alone. They must be interfaced to traditional military systems to operate jointly. One operating concept for such a networked modern warfare is the combat cloud, which

was first released by US Air Force in March 2016 [1], [2].

An interesting question is, how the pre-mentioned new technologies will change the warfare? How does the use of the traditional weapon systems change, once the autonomous systems and sensors are utilized? What kind of completely new ways to operate do they provide, and are they making some currently applied methods useless in the nearby future?

This article discusses about these questions based on the experiences from MULTICO project executed on 2020-22. The project was supported by Business Finland, and the consortium had members from the industry and academia including also the National Defence University of Finland (NDU) and Finnish Air Force Academy (FAFA) in the advisory role. In addition to sensor systems, there were two rapidly developing technologies considered in this project: multirotor (multicopter) type of drones and small satellites. Both of them can be equipped with one or several types of sensors (including cameras) and actuators. In multirotor drones, the sensors can be either mounted to the drone so that they make their measurements in the air during the flight, or they can be deployed to the ground by the drone [3].

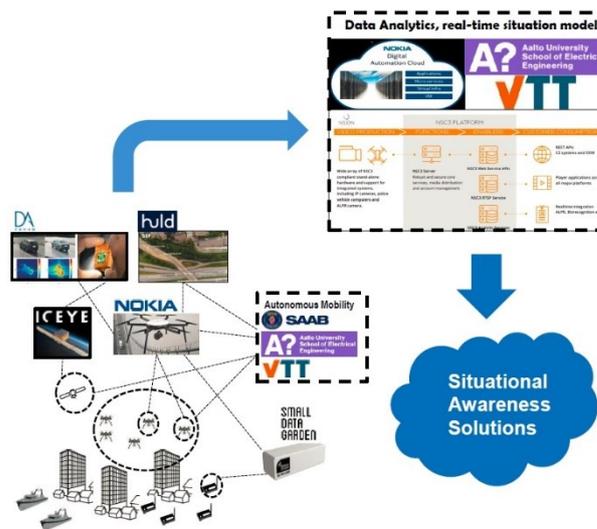


Figure 1 A system level view of MULTICO architecture.

As a part of their advisory role, NDU and FAFA defined

a list of performance requirements and respective test scenarios, which were focusing on surveillance and airbase protection. MULTICO system developed in the project was first tested in the winter experiments in December 2021 and towards the end of the project in final experiments in September 2022.

2 Methods

The research consists of author's discussions and brainstorming with the Air Combat Center of Finnish Air Forces (FAF), experiences from FAF exercises and the content of MULTICO project, which includes case studies in the form of MULTICO winter and final experiments [3]. Later experiences from Russo-Ukrainian war and other crisis are also utilized in the further analysis of MULTICO results and in the conclusions about the future work.

3 Results and Conclusions

Developed architecture was able to operate as one entity, or its subsystems can operate on their own. Communication and computation architecture, cabled and wireless flying base stations, deployable LoRaWAN sensor network, Saab Sirius Compact sensor and Iceye's small satellite system operated successfully in the experiments. Some of these subsystems are already commercialized and all of them are reaching that technology maturity level.

Developed GNSS free navigation methods behaved promisingly [4], but more research and development work is still needed to reach the level of productization and commercialization. Iceye's small satellite SAR data reding and analysis should be integrated to the same COP as the rest of the system [3].

A software for deployable wireless BLE mesh network was completed [5], but the hardware must be re-designed to make it suitable for field conditions and drone deployment. Preliminary results about radio tomographic detection of the presence of people and their tracking by using software defined radios in drones were achieved, but further research is still needed to improve system accuracy and reliability.

The most important factor the multirotor drones can improve is to achieve and share the advance information about the situation and its changes as early as possible. Multirotor drones provide a view to the base area from the air. It is also flexible to change the point of view by moving them from one location to another and by zooming and changing the angle of view when hovering in one location, if there is something interesting to observe further. Night vision capability is

necessary, and the simultaneous availability of daylight and night vision cameras support each other when making the observations.

When equipped with radar or suitable sensors, friendly drones can observe enemy drones and their data traffic from the air, and also disturb them. An important direction to investigate further is the possibility to use multirotor drones to obfuscate missiles.

The property to deploy sensor networks on the ground using multirotor drone is very useful. Deployed sensor networks can be used for the securing and monitoring of targets, and also for surveillance and for harassing the enemy. However, the reliability of the sensor systems in different weather and electromagnetic spectrum conditions is a critical factor.

Wireless flying cellular base station is a good way to establish rapidly an efficient temporal network. Cell area can be limited based on the particular need, and the cell can also move with the group it serves. Cabled flying base station is rapid to set up and disassemble compared to the tactical mast.

A fundamental thing, that must be solved to use multirotor drones in the airbase area during the air operations, is the drone location information sharing with the air traffic control. Drones must be included to the same airspace management with other aircraft.

4 Bibliography

- [1] Lester, J. and Vieira, R., United States Air Force Combat Cloud Operating Concept, March 2016.
- [2] Kiser, A., Hess J., Bouhafa, E. M. and Williams, S., The Combat Cloud – Enabling Multi-Domain Command and Control Across the Range of Military Operations, Air Command and Staff College, Air University, Maxwell Air Force Base, Alabama, March 2017.
- [3] Virrankoski, R. (ed.), Autonomous Sensing using Satellites, Multicopters, Sensors and Actuators (MULTICO) – Final Report, Aalto University, Department of Information and Communications Engineering, 2023.
- [4] Kinnari, J., Infrastructureless unmanned aerial vehicle localization, Doctoral dissertation, Aalto University, Department of Electrical Engineering and Automation, 2024.
- [5] Wang, W., Performance Evaluation of Deployable Bluetooth Low Energy Mesh Network for Monitoring System, Master's Thesis, Aalto University, Department of Information and Communications Engineering, 2022.

Lauri Aaltonen* ja Kari Lappalainen

Energiamurroksen vaikutukset sähkönkulutukseen ja -tuotantoon suomalaisissa jakeluverkoissa

Tiivistelmä: Tämä artikkeli käsittelee meneillään olevan energiamurroksen vaikutuksia sähkönkulutukseen ja -tuotantoon suomalaisissa sähkönjakeluverkoissa, keskittyen pääpainoltaan Tampereen Energia Sähköverkko Oy:n verkkoalueeseen. Energiamurros, joka sisältää energiatehokkuuden parantamisen sekä siirtymisen uusiutuviin energialähteisiin, muuttaa merkittävästi sähkönjakeluverkkojen toimintaa. Tutkimus pyrkii analysoimaan, miten energiamurros näkyy jo nyt verkkoyhtiöiden toiminnassa ja millaisia historiallisia trendejä on havaittavissa. Tulokset osoittavat pientuotantolaitosten kasvavan verkossa sekä lukumäärältään että tehoiltaan. Uudet asiakkaat hankkivat suurempia liittymiä ja osa vanhoista asiakkaista korottaa liittymäsopimustaan. Tuloksia on mahdollista hyödyntää esimerkiksi sähkönjakelu- ja rakennusautomaatiota suunniteltaessa.

Avainsanat: energiamurros, sähkönjakeluverkko, hajautettu tuotanto, liikenteen sähköistyminen

***Vastaava kirjoittaja:** Lauri Aaltonen Tampereen yliopisto, E-mail: lauri.aaltonen@tuni.fi

Kari Lappalainen: Tampereen yliopisto, E-mail: kari.lappalainen@tuni.fi

1 Johdanto

Energiamurros on meneillään oleva energiasektorin rakenteellinen muutos, jossa perinteiset fossiilisiin polttoaineisiin perustuvat energiantuotantotekniikat korvataan uusiutuvilla energialähteillä ja energiatehokkuutta parantavilla ratkaisuilla. Tämä on yksi keinoista päästä Pariisin ilmastopöytäkirjan tavoitteisiin vuoteen 2050 mennessä.

Jakeluverkkotasolla energiamurroksen tuomat muutokset liittyvät pääasiassa sähköistymiseen, uusiutuvaan sähköenergiantuotantoon ja energiatehokkuuteen. Sähköistys, suoraan tai epäsuoraan, näkyy muun muassa liikenteen, lämpöjärjestelmien ja teollisten prosessien keskuudessa. Uusiutuvan, sääriippuvan, tuotannon määrä on kasvanut. Kansainvälinen energijärjestö (IEA) ennustaa uusiutuvien kattavan koko maailman

sähköntuotannosta melkein puolet vuoteen 2030 mennessä, tuulivoiman ja aurinkovoiman osuuksien kaksinkertaistuessa noin 30 %:iin [1]. Energiatehokkuus on myös näkyvä osa energiamurrosta esimerkiksi lämmitystaparemonttien ja sähkönkäyttäjien aktiivisuuden lisääntymisen muodossa.

Energiamurros tuo haasteita jakeluverkkoyhtiöiden toimintaan. Tampereen Energia Sähköverkko Oy ennustaa vuoden 2024 kehittämissuunnitelmassaan sähköautojen ja pientuotannon määrän kasvavan seuraavan 10 vuoden aikana reippaasti [2]. Sääriippuvaisen hajautetun tuotannon ja uusien kuormien liittämisen verkkoon tulee olla mahdollista samanaikaisesti mahdollisten joustopalveluiden kanssa. Näiden haasteiden vallitessa jakeluverkkoyhtiöiden tulisi suunnitella verkkoinvestointejaan pitäen samalla kustannukset, turvallisuuden ja verkon luotettavuuden halutulla tasolla.

Tämä artikkeli analysoi erilaisia energiamurrokseen liittyviä sähkönkäytön muutostrendejä sähkönjakeluverkoissa Suomessa. Tarkoituksena on saada konkreettista tietoa siitä, mitkä lähiaikoina tapahtuneet muutokset ovat merkittäviä jakeluverkon suunnittelun näkökulmasta.

2 Menetelmät ja aineisto

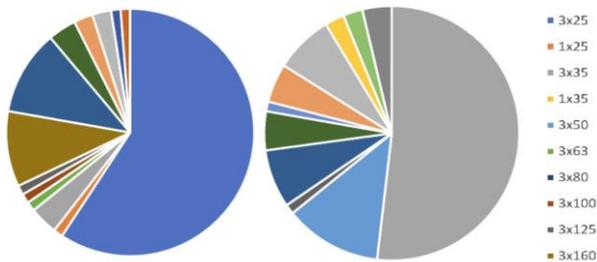
Tutkimuksessa hyödynnetään yhden manner-Suomen jakeluverkkoyhtiön, Tampereen Energia Sähköverkko Oy:n (TAES), dataa sähkönkulutuksesta ja -tuotannosta saatavilla olevan julkisen datan lisäksi. Yhtiö toimii pääasiassa Tampereen kaupungin alueella käsittäen useita erilaisia alueita kuten ydinkeskustan, teollisuusalueita, taajama-alueita ja haja-asutusalueita.

Tietoa on haettu TAES:in verkko-, energia- ja asiakastietojärjestelmistä. Verkkotietojärjestelmästä on saatu tietoa jakeluverkon nykyisistä komponenteista sekä niiden ikärakenteesta ja pitoajoista. Asiakastietojärjestelmässä puolestaan on tietoa solmituista liittymissopimuksista. Energiatietojärjestelmässä on saatavilla asiakkaiden sähkönkulutustiedot.

3 Tulokset

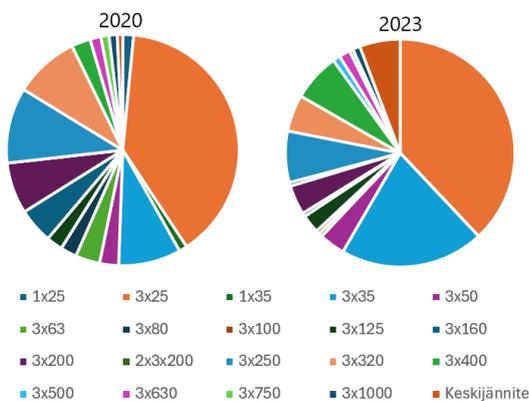
Liittymäsopimusten muutoksia tarkasteltiin vuosilta 2020–2023. Tieto liittymäsopimuksen muutoksesta on verkkoyhtiölle tarpeellinen, sillä kulutustottumukset muuttuvat tällä hetkellä radikaalisti esimerkiksi lämmitystaparemonttien tai sähköautojen hankinnan seurauksena. Kaikista 668:sta saatavilla olevista tarkastellusta liittymäsopimuksen muutoksesta 59 % oli vanhan 3x25 A:n sulakekoon liittymien muutoksia. Toiseksi suosituin korotettava liittymä oli 3x160 A, 7 %:n osuudella.

Kuvassa 1 esitetään vuoden 2023 liittymäsopimusmuutokset. Kun tarkastellaan liittymäsopimusten muutoksia, voidaan havaita, että valtaosa vanhoista liittymistä on 3x25 A-liittymiä ja uusista 3x35 A-liittymiä. Vuonna 2023 120 kpl 3x25 A-liittymiä päivitti liittymäkokoaan isompaan. 95 % vaihtoi seuraavaan mahdolliseen, 3x35 A:n liittymään ja loput joko 3x50 A:n tai 3x63 A:n liittymään.



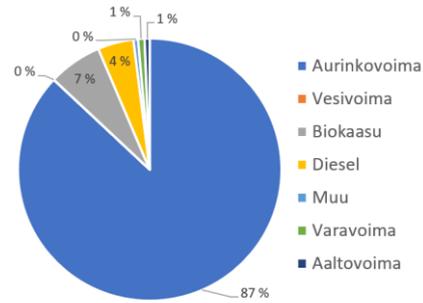
Kuva 1. Liittymäsopimusten muutokset vanhasta (vas.) liittymästä uuteen (oik.) vuonna 2023

Uusia liittymiä on otettu käyttöön 2020 alusta vuoden 2023 lokaan alkuun 1204 kappaletta. Kuvassa 2 on esitetty uudet liittymät TAES:n verkkoalueella. Uusissa liittymissä näkyy samanlainen trendi mitä liittymäsopimusten muutoksissa. Koon 3x25 A-liittymä on menettänyt suosiotaan ja 3x35 A on kasvattanut suosiotaan. Muita liittymiä on verrattain vähän, joten niistä on vaikeampi havaita trendiä luotettavasti.



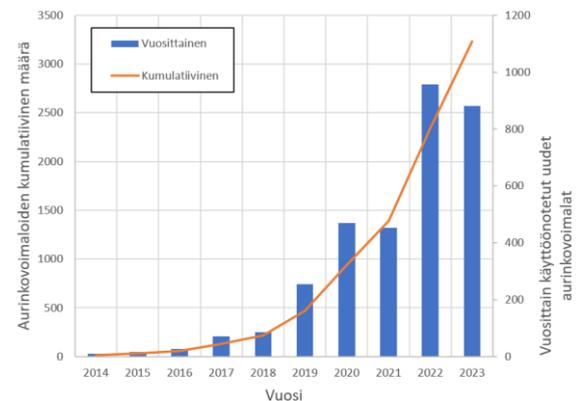
Kuva 2. Uusien liittymien sulakekoko vuosina 2020 ja 2023.

Aurinkovoimalat yleistyvät verkossa kansallisesti. Vuonna 2017 aurinkovoimalat tuottivat Suomessa sähköenergiaa 49 GWh. Vuonna 2022 vastaava luku oli 392 GWh. [3] Dataa tutkittavan verkkoalueen aurinkovoimaloista on haettu viimeisen 10 vuoden ajalta. Kuvassa 3 on Tampereen Energia Sähköverkko Oy:n verkkoalueen kaikki pientuotantopaikat (< 1 MW) esitettyä tuotantotavan mukaan. Kuvaajasta voidaan havaita, että valtaosa pientuotannosta painottuu aurinkovoimaan. Kaasu- ja dieselvoimaa on myös huomattava määrä.



Kuva 3. Pientuotannon (< 1 MW) tuotantomuodot verkkoalueella, nimellistehon mukaan.

Kuvassa 4 on esitetty alle 1 MVA:n aurinkovoimaloiden kumulatiivinen lukumäärä ja vuosittainen käyttöönotettujen voimaloiden lukumäärä TAES:n verkkoalueella. Kumulatiivinen käyrä nousee hyvin jyrkästi, vaikka viimeisimpänä vuonna asennusten määrä ei ole enää ollut kasvussa.

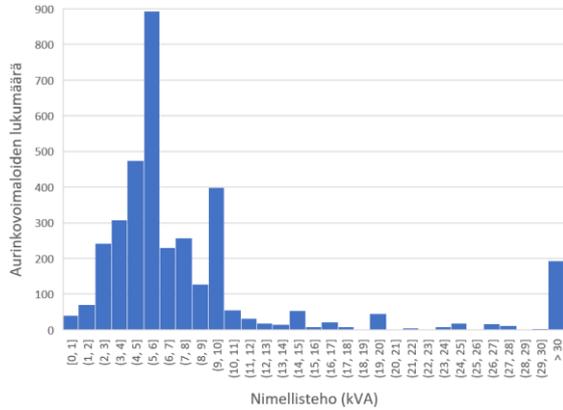


Kuva 4. Alle 1 MVA:n aurinkovoimaloiden yleistyminen verkossa kappalemäärinä.

Kuvassa 5 on esitetty verkkoalueen aurinkovoimalat jaoteltuna nimellistehon mukaan. Kuten voidaan havaita, suosituin aurinkovoimalan teholuokka on 5–6 kVA. Huomattavaa on myös 9–10 kVA:n aurinkovoimaloiden yleisyys. Yli 30 kVA:n voimaloita on myös huomattava määrä.

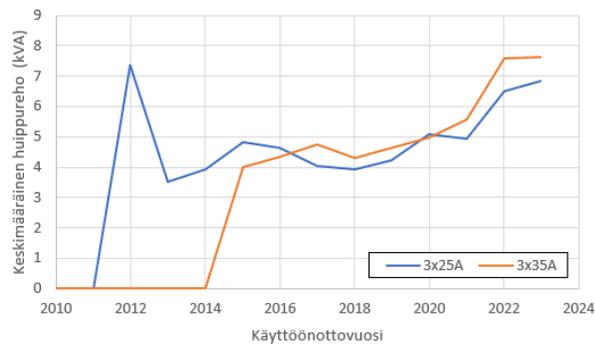
Kuvassa 6 esitetään aurinkovoimaloiden keskimääräistä nimellistehoja kahden tyyppillisen omakotitalon pääsulakekoon kohteissa. Vuosina 2010–

2014 asennetuissa voimaloissa keskimääräinen nimellisteho heittelehtii paljon, voimaloiden pienen määrän vuoksi. Viimeisimmän viiden vuoden aikana tilanne on muuttunut huomattavasti. Vuonna 2018 nimellistehojen keskiarvot olivat noin 4–5 kVA ja 2023 ne olivat jo 6–8 kVA.



Kuva 5. Aurinkovoimaloiden nimellistehojen jakautuminen

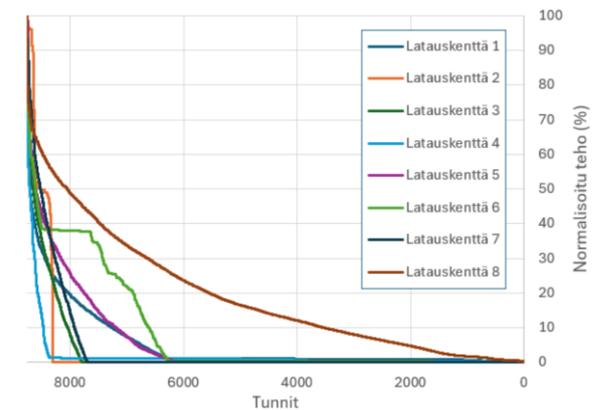
Aurinkovoimaloiden kasvu verkkoalueella johtaa myös pitkällä aikavälillä kehittyneempiin automaatiotratkaisuihin. Suurin osa tuotetusta aurinkoenergiasta halutaan käyttää mahdollisuuksien mukaan itse. Tämä vaatii automaatiotratkaisuja kiinteistön kuormiin tai jopa tarvetta energiavarastoille. Jakeluverkkoyhtiöllä on taas omat tavoitteensa, jotka poikkeavat sähkökuluttajasta. Näitä ovat esimerkiksi joustopalvelut ja mahdolliset saarekekäytöt.



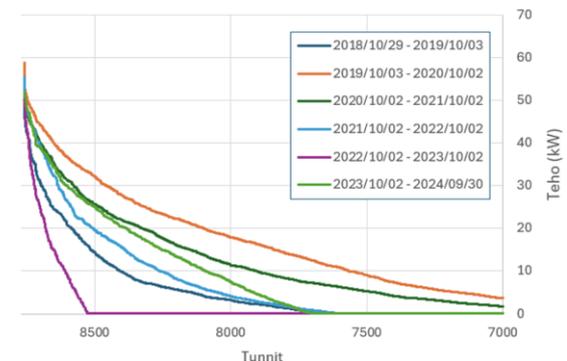
Kuva 6. Aurinkovoimaloiden nimellistehon keskiarvo käyttöönottovuoden funktiona kahden eri sulakekoon kohteissa.

Sähköautojen latauspisteistä on saatavilla vähemmän dataa, sillä latauspisteen lisäyksestä ei tarvitse kertoa verkkoyhtiölle, ellei laturi kykene kaksisuuntaiseen lataukseen. Isompia, julkisia sähköautonlataukseen tarkoitettuja liittymiä TAES:n verkkoalueelta löytyy ja ne löytyvät verkkotietojärjestelmästä julkista tietoa olevan sijaintinsa avulla. Kuvassa 8 on esitetty 7 liittymän pysyvyyskäyrät viimeisimmän vuoden ajalta normalisoituna liittymän maksimitehon mukaan. Liittymät toimivat tyypillisesti suurimman osan

vuodesta nollassa. Pienen osan ajasta liittymät toimivat maksimiteholla. Lisäksi latauskenttien hallinnoijat voivat esimerkiksi rajoittaa lataustehoja eri latuereille liittymän takana ja suorittaa huoltotoimenpiteitä. Pysyvyyskäyrän selkeistä "askelistista" voi havaita sen, miten liittymän maksimitehoa jakautuu oletettavasti eri latuereiden kesken. Latauskenttä 8 on ainoa tarkasteltu keskijänniteliittymä. Tämän liittymän takana on luultavasti muutakin kuormaa, mikä selittäisi pysyvyyskäyrän muodon pienillä tehoilla. Liittymässä tiedetään olevan myös sähköautonlatausta, joka näkyy pysyvyyskäyrän huipussa. Sulakekoon 3x160 A:n sulakkeiden takana olevalle latauskenttä 7:lle on esitetty pysyvyyskäyrät eri vuosina kuvassa 9. Kuvaajasta voidaan havaita suurta vaihtelua latauskentän käytössä eri vuosien välillä. Kilpailevat toimijat sekä palvelut lähialueella voivat muuttaa latauskentän käyttöä voimakkaasti. Muita mahdollisia syitä muutoksiin ovat huolto- ja ylläpitotoimenpiteet, laitteiston päivitykset ja muutokset latauspalvelun hinnoittelussa.



Kuva 7. Liittymän maksimitehon mukaan normalisoitu pysyvyyskäyrä 7:lle julkiselle latauskentälle.



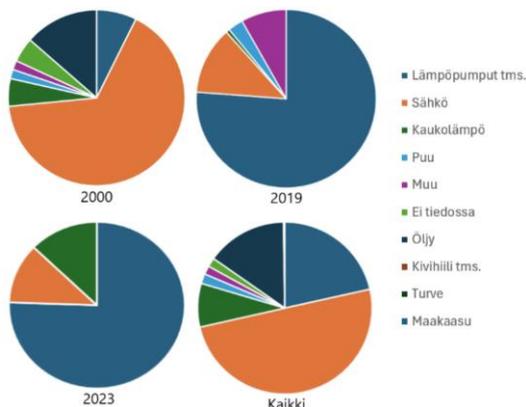
Kuva 8. Pysyvyyskäyrä eri vuosilta latauskenttä 7:lle.

Nykyisiä, pääasiassa passiivisia latauskenttiä tullaan tulevaisuudessa käyttämään aktiivisemmin. Tämä tarkoittaa, että latauskenttää ohjataan kulujen optimoimiseksi esimerkiksi ostetun sähkön hinnan suhteen sekä kuorman tasoittamiseksi samalla pitäen asiakkaiden tyytyväisyyden latauspalveluun riittävänä

esimerkiksi tarpeeksi nopean latauksen, luotettavuuden ja selkeän hinnoittelun avulla. Tämän toteuttaminen tehokkaasti vaatii uusia automaatiotratkaisuja.

Suomalaisten kiinteistöjen lämmitystavat ja energiatehokkuudet ovat muuttuneet mm. fossiilisten polttoaineiden hintojen kasvun seurauksena. Yksi tyypillisimmistä remonteista on öljylämmityksestä luopuminen ja lämmitystavan vaihto esimerkiksi erilaisiin lämpöpumpputeknikoihin. Vuosina 2020–2024 ELY-keskuksen tähän tarkoitukseen myöntämän valtionavustuksen määrä oli yhteensä 122 M€. Tampereen alueella noin 2,3 % pientalokannasta hyödynsi tätä avustusta samalla ajanjaksolla. [4]

Mitä enemmän kiinteistöjä siirrytään lämmittämään puun, öljyn tai kaasun sijasta suoralla sähköllä tai epäsuoralla sähköllä esim. maalämpöpumppujen avulla sen suurempi sähkönkulutus verkossa on. Kasvu pätee myös huipputehoille, ellei lämmityksiä ajoiteta järkevästi. Kuvassa 9 on esitetty Tampereen alueen omakotitalojen lämmitystapa [5] eri vuosina rakennetuissa taloissa, lämmitysvoiman mukaan jaoteltuna. Datasta on suodatettu pois kohteet, joiden rakennustilavuudeksi on ilmoitettu 0 m³.



Kuva 9: Tampereen omakotitalojen lämmitystapa eri vuosina rakennetuissa kohteissa [5].

Rakennusdatasta voidaan havaita monta muutosta. Öljylämmitteisiä omakotitaloja rakennettiin vielä 2000-luvun alussa jonkin verran, mutta enää ei liki ollenkaan. Öljylämmitteisten omakotitalojen osuus nykyisestä rakennuskannasta on vielä kuitenkin huomattava. Toisaalta vuosituhannen vaihteessa suosittu sähkölämmitys ei ole enää yhtä suosittu ja sen jättämää aukkoa ovat korvanneet erilaiset lämpöpumppuratkaisut.

4 Yhteenveto

Tämän artikkelin tarkoituksena oli selvittää energiamurroksen trendejä suomalaisissa

sähkönjakeluverkoissa. Pientuotannon määrän havaittiin kasvaneen voimakkaasti sekä verkossa olevan kapasiteetin että yksittäisen voimalan tehon suhteen. Samaan aikaan sähköautot ja lämmitystapamuutokset ovat kasvattaneet sähkökäyttöä. Sähköautojen latauskenttien pysyvyyskäyrät ovat jyrkkiä ja vuosittainen vaihtelu on merkittävää.

Sääriippuvan tuotannon ja sähköajoneuvojen kasvu johtaa isompiin tehoihin ja energiankäyttöön verkkoalueella. Muutokset sähköverkossa kasvattavat uusien automaatiotratkaisujen kysyntää. Automaatiotratkaisuja täytyy kehittää sekä kuluttajille että verkkoyhtiöille sillä molemmilla on omat tavoitteensa, jotka eivät aina kohtaa. Esimerkiksi kuluttajat saattavat keskittyä pääasiassa säästöihin, kun verkkoyhtiöt taas saattavat painottaa verkon luotettavuutta. Tulevaisuudessa automaatiojärjestelmät tulevat olemaan keskeisessä roolissa energiajärjestelmien optimoinnissa.

Tunnustukset

Kirjoittajat haluavat kiittää Tampereen Energia Sähköverkko Oy:tä tutkimuksen lähtötiedoista. L. Aaltonen on saanut rahoitusta Teollisuuden innovaatioiden tohtorikoulu (DSII) -projektista, jota rahoittaa Tampereen Energia Sähköverkko Oy sekä Tampereen yliopisto. K. Lappalainen on saanut rahoitusta Suomen Akatemialta (rahoituspäätös 348701).

Lähteet

- [1] Kansainvälinen energiajärjestö (IEA), Renewables 2024 [verkkajulkaisu], <https://www.iea.org/reports/renewables-2024>, s. 9. Lisenssi: CC BY 4.0. Viitattu: 2025-03-02.
- [2] Tampereen Energia Sähköverkko Oy, Kehittämissuunnitelma 2024 [verkkajulkaisu]. <https://tampereensahkoverkko.kehittamissuunnitelma.fi/>. Viitattu: 2025-03-06.
- [3] Tilastokeskus. Suomen virallinen tilasto (SVT): Sähkön ja lämmön tuotanto [verkkajulkaisu]. <https://stat.fi/tilasto/salatuo>. Viitattu: 2024-10-09.
- [4] Elinkeino-, liikenne- ja ympäristökeskus (ELY-keskus): Avustus pientalon öljylämmityksestä luopumiseksi – Avustusten karttasovellus [verkkajulkaisu]. <https://experience.arcgis.com/experience/cac6442d52b94b0c913d39ddc57ec549/>. Viitattu: 2025-02-17.
- [5] Tampereen kaupungin dataportaali. Tampereen rakennukset [verkkajulkaisu]. <https://data.tampere.fi/data/fi/dataset/tampereen-rakennukset>. Viitattu: 2024-11-13.

Olli Väänänen* ja Karo Saharinen

Automaatiotekniikan kyberturvallisuuden koulutus- ja testausympäristö

Tiivistelmä: Huoltovarmuuskeskus tilasi Jyväskylän ammattikorkeakoululta esiselvityksen, jolla selvitettiin korkeakoulujen mahdollisuuksia ja kiinnostusta erilaisten automaatiojärjestelmien kyberturvallisuuden koulutus- ja testausympäristön luomiseksi. Ympäristö olisi yhteiskäyttöinen ja dedikoiduilla yhteyksillä toteutettu verkosto. Kysely kohdennettiin suomalaisille korkeakouluille, joilla on aiheeseen liittyvää koulutusta. Kysely toteutettiin syksyn 2024 aikana kahtena erillisenä kyselytutkimuksena. Kyselyn tuloksena voidaan todeta, että aihe herättää mielenkiintoa ja koetaan tarpeelliseksi. Aiheeseen liittyviä käytännön toimenpiteitä on tehty vasta muutamassa korkeakoulussa. Toteutuessaan verkosto tukisi erityisesti alueellista osaamista.

Keywords: kyberturvallisuus, automaatiotekniikka, koulutus

***Olli Väänänen:** Jyväskylän ammattikorkeakoulu, E-mail: olli.vaananen@jamk.fi

Karo Saharinen: Jyväskylän ammattikorkeakoulu, E-mail: karo.saharinen@jamk.fi

1 Johdanto

Realistic Automation Cyber Environment, preliminary investigation (RACEPI) -esiselvityksen toteutti Jyväskylän ammattikorkeakoulun JYVSECTEC, ja sen tavoitteena oli kartoittaa mahdollisuudet ja kiinnostus automaatiojärjestelmien ja niiden sensoreiden kyberturvallisuuden koulutus-, harjoittelu- ja testausympäristön luomiseksi. Itse Realistic Automation Cyber Environment - RACE:n tavoitteena mahdollisesti toteutuessaan olisi teollisuuden ja talotekniikan eri automaatiojärjestelmistä, sensoreista ja niitä simuloivista palveluista koostuva, dedikoiduilla yhteyksillä toteutettu verkosto, jossa voitaisiin tutkia niihin kohdistuvien kybervaikutusten menestystä ja harjoitella kybervaikuttamisen vastatoimia.

Selvityksen toteuttaja JYVSECTEC – Jyväskylä Security Technology – on riippumaton kyberturvallisuuden tutkimus-, kehitys- ja koulutuskeskus, joka toimii osana Jyväskylän ammattikorkeakoulun IT-instituuttia. Tämä

RACEPI-selvitys kohdistettiin suomalaisille korkeakouluille, ja sen tilaajana toimi Huoltovarmuuskeskus. Kysely toteutettiin syksyn 2024 aikana.

2 Menetelmät

Esiselvitys toteutettiin kahdessa vaiheessa syksyllä 2024 Webropol-työkalulla. Aluksi lähetettiin sähköpostitse tiedustelu 24 korkeakoululle, joista yhteensä 12 ilmaisi kiinnostuksensa osallistua tarkempaan kyselyyn. Varsinainen kysely lähetettiin näille korkeakouluille, ja määräaikaan mennessä saatiin vastaukset kahdeksalta korkeakoululta, sekä kaksi myöhässä tullutta vastausta. Yhteensä vastauksia saatiin siis kymmeneltä korkeakoululta.

Kyselyn tulokset analysoitiin ja esiteltiin RACEPI-hankkeen ohjausryhmälle. Johtopäätöksenä yhdessä ohjausryhmän kanssa alun perin suunnitellusta haastattelukierroksesta luovuttiin, mutta sen sijaan järjestettiin täydentävä lisäkysely kyselyn ensimmäiseen osioon vastanneille. Lisäkyselyyn vastasi yhteensä seitsemän korkeakoulua. Myös lisäkyselyllä täydennetyt analysoinnin tulokset esiteltiin hankkeen ohjausryhmälle.

Kyselyiden pohjalta on laadittu kattavampi loppuraportti, joka on toimitettu kyselyiden raakadatan kanssa toimeksiantajalle.

3 Tulokset

Kyselyn ensimmäisessä vaiheessa kartoitettiin muun muassa, kuinka paljon erilaisia aiheeseen liittyviä tutkinto-ohjelmia kullakin korkeakoululla on. Tuloksena oli listattuna suuri määrä tutkinto-ohjelmia sekä alempia korkeakoulututkinnosta, että ylemmistä tutkinnoista. Pääasiassa tutkinto-ohjelmat olivat joko tieto- ja viestintäteknikan koulutusosalta tai sähkö- ja automaatiotekniikan koulutusosalta. Myös yksittäisiä talotekniikan, energia- ja ympäristötekniikan sekä konetekniikan tutkinto-ohjelmia oli listattuna.

Toinen pääteema kyselyssä oli selvittää millaisia aiheeseen liittyviä IoT- ja OT-järjestelmiä oppilaitoksilla

on käytettävissä. Kysely paljasti, että korkeakouluissa käytetään laajasti erilaisia IoT- ja OT-järjestelmiä eri tutkinto-ohjelmissa, erityisesti tieto- ja viestintäteknikan sekä sähkö- ja automaatiotekniikan aloilla. Listatut järjestelmät pitivät sisällään muun muassa erilaisia IoT-järjestelmiä, automaatiojärjestelmiä, ohjelmoitavia logiikoita, robotteja ja robottisoluja sekä rakennusautomaatio ja kiinteistön hallintajärjestelmiä. Useimmat korkeakoulut olivat kytkeneet nämä järjestelmät omiin tietoverkkoihinsa tai internetiin etäkäyttöä varten. Kuviossa 1 näkyy vastausten jakautuminen liittyen kysymykseen miten kyseiset järjestelmät ovat kytketty.



Kuvio 1. IoT- ja OT-järjestelmien kytkeminen mahdolliseen tietoverkkoon.

Järjestelmien ylläpidosta vastaavat yleensä dedikoidut laboratoriohenkilöstöt tai opetushenkilöstö. Kuviossa 2 näkyy vastausten jakautuminen kyseiseen kysymykseen. Muu, mikä? kysymyksen vastauksissa oli mainittu muun muassa järjestelmätoimittajat sekä tutkijat.



Kuvio 2. Järjestelmien ylläpito

Selvityksessä kysyttiin myös, onko aikaisemmin mainittuihin IoT- ja OT-järjestelmiin kohdistettu kybervaikuttamista opetustarkoituksessa. Tuloksista selvisi, että kyberturvallisuuteen liittyviä toimintoja oli rajoitetusti, mutta muutama korkeakoulu listasi opintojaksoja sekä toimia mitä aiheeseen liittyen oli jo tehty. Osassa korkeakouluista oli tehty aiheeseen liittyviä opinnäytetöitä ja osalla on suunnitelmia

aiheeseen liittyen. Kokonaisuutena toiminta vaikuttaa olevan vielä varsin pienimuotoista.

Suurin osa vastaajista koki IoT- ja OT-järjestelmiensä olevan mahdollista kytkeä yhteiskäyttöiseen ympäristöön ja heillä olevan valmiudet siihen. Muutama korkeakoulu oli jo testannut tällaisia yhteiskäyttöisiä ympäristöjä.

Kyselyn toisessa vaiheessa kysyttiin mitä tutkimusta tai testaus- ja tuotekehitystä RACE voisi tukea alueellisesti ja globaalisti sekä minkä tutkimuksen tai testaus- ja tuotekehityksen edellytys RACE olisi. Vastaukset vaihtelivat paljon. Useammassa vastauksessa korostettiin alueellisen osaamistason nostamista ja kohdistuen PK-yrityksiin. Teollisuusautomaatio ja lisäksi mm. kiinteistöautomaatio nousi aihealueina esille vastauksista. Myös konesalitoimijat sekä esimerkiksi sähköverkkoautomaatio kriittisen infrastruktuurin toimintena löytyi vastauksista. Kaiken kaikkiaan RACE:n merkitys koetaan erityisesti kehitysympäristön mahdollistajana ja se palvelisi erityisesti PK-yrityksiä ja mahdollistaisi realistisemman testaus- ja tuotekehitysympäristön alueellisille toimijoille.

4 Johtopäätökset

Korkeakouluilla on hyvin laajasti erilaisia IoT- ja OT-ympäristöjä, joita olisi mahdollista yhdistää osaksi RACE-ympäristöä. Mahdollinen RACE-verkosto ja sen perustamiseen tarvittava hanke herättää kiinnostusta ja sellainen koetaan tarpeelliseksi. Hanke ja sen kautta rahoitus tarvitaan, jotta asia etenisi ja toimijat saataisiin sitoutumaan asiaan. Lisäksi toiminnan jatkuvuus tulisi varmistaa myös hankkeen jälkeen.

Osalla korkeakouluista on aiheeseen liittyvää toimintaa ja kehitystyötä sekä tutkimusta. Se jatkuisi niiden osalta myös ilman hanketta, mutta RACE helpottaisi tilannetta. RACE:n avulla mukaan saataisiin myös sellaisia korkeakouluja, jotka eivät nykyisellään pysty merkittävästi edistämään aiheeseen liittyvää koulutusta ja TKI-toimintaa.

Esiselvitys osoitti, että suomalaisissa korkeakouluissa on merkittävää kiinnostusta ja potentiaalia RACE-ympäristön luomiselle. Tällainen ympäristö tukisi automaatiojärjestelmien kyberturvallisuuden koulutusta ja tutkimusta, hyödyttäen sekä akateemisia instituutioita että teollisuusympäristöjä. Selvitys toi esiin myös rahoituksen ja selkeän vastuunjaon tarpeen, jotta RACE-verkoston toteutus ja jatkuvuus voitaisiin varmistaa. Selvityksen tulokset on luovutettu Huoltovarmuuskeskukselle, joka päättää mahdollisista jatkotoimenpiteistä.

Teijo Juntunen*, Alex Kanerva, Antti Ranta, Sami Repo, David Hästbacka, and Matti Vilkkö

Framework for the Quantification of the Process Flexibility in Industrial Processes

Abstract: This paper presents a framework for quantifying process flexibility in energy-intensive industrial (EII) sectors, such as metal manufacturing, wastewater treatment, and glass container manufacturing. The methodology involves four steps: identifying energy flexibility sources, creating an optimization model, calculating upper and lower energy consumption limits, and validating the model's functionality. The framework is applied to two EII processes: a feeder process in a glass container factory and an aeration process in a wastewater treatment plant. The optimization model minimizes energy consumption while maintaining process constraints, and the results are validated through more accurate models and real-world testing. This approach aims to enhance the profitability of factories by leveraging variations in electricity prices and novel electricity market flexibility products and services.

Keywords: flexibility, optimization, demand response

***Corresponding Author: Teijo Juntunen:** Tampere University, E-mail: teijo.juntunen@tuni.fi

Alex Kanerva: Tampere University, E-mail: alex.kanerva@tuni.fi

Antti Ranta: Tampere University, E-Mail: antti.ranta@tuni.fi

Sami Repo: Tampere University, E-mail: sami.repo@tuni.fi

David Hästbacka: Tampere University, E-mail: david.hastbacka@tuni.fi

Matti Vilkkö: Tampere University, E-mail: matti.vilkkö@tuni.fi

1 Background

The energy sources used by industry are becoming increasingly volatile. This has created a need to identify flexibility potentials, especially in processes within energy-intensive industrial (EII) sectors, e.g. metal manufacturing, wastewater treatment, and glass container manufacturing. Knowing the flexibility potential of processes enables using the variations in electricity prices and novel products and services of the electricity market to improve the profitability of factories.

Flexibility sources external from the process are, for example, solar panels, material storage, or batteries. In addition to these sources, it is also beneficial to identify and model the internal flexibilities of the processes

in question. However, quantifying the internal process flexibility is not as apparent as quantifying external flexibility such as the capacity of the battery or a storage container.

Previously, the running methods of continuous processes have been well established and the internal flexibility of the processes has been used mainly to ensure robustness. In this case, the need for flexibility has been very predictable and constant. However, in the future, the flexibility potential used can vary very significantly on a daily basis.

2 Aims

To challenge the established methods of process control, a credible, teachable and reproducible framework is needed to quantify the implicit flexibility in each process. In this work, this universal framework for flexibility quantification is created, and its applicability is tested by implementing it to two different EII processes: A feeder process for a glass container factory and the aeration process of a waste water treatment plant.

The framework needs to be able to calculate the optimal energy consumption and the possible upper and lower limits for the energy consumption during each time step.

3 Materials and Methods

The designed framework consists of four steps:

1. Identifying the energy flexibility sources from the process
2. Creating the optimization model for the process
3. Using the created optimization model to calculate the upper and lower limits of energy consumption for each time step
4. Validating the functionality and outputs of the optimization model

In the first step, the process state-of-the-art is thoroughly studied with the help of process engineers, op-

erators, and literature. The aim is to find overcapacity or physical storages, which would imply that there is flexibility in the process. The process of identifying the flexibility potentials are studied more thoroughly in [1]

The next step is to formulate the governing equations of the process using mass and energy balances. Often, the existing process equations might be complex or non-linear, which, for the sake of computational efficiency, need to be simplified or approximated to be linear. Any optimization methods and formulations are applicable as long as they converge reliably within the allocated time and are deemed accurate enough in the validation step. Additionally, in the third step, the process constraints are assessed and then formulated into the optimization model.

After the optimization model is developed, it is first used to calculate the minimum energy consumption of the process for the desired optimization horizon. This is the baseline with which the upper and lower limits of the process are then described. Using the cost structure of the optimization model, we then proceed to weigh each step with higher and lower costs compared to the other step costs. Higher cost result giving the lowest limit for energy usage during that step and lower cost giving the highest limit for energy usage during that step. These limits are calculated for all steps in the optimization horizon.

The calculated limits and the corresponding decision variable values are then given as an output of the flexibility quantification to e.g decision support system (DSS) or energy management system (EMS). Before deployment and integration to the control system, the given values have to be validated to be accurate enough in the validation step. If the model is not accurate enough, it will be refined by returning to step two of the quantification sequence. After the model is validated, it is ready to be deployed and integrated into the process control system[2].

In the next two subsections we implement this framework into two different EIIs: Glass container manufacturing and wastewater treatment.

3.1 Feeder process flexibility quantification

In the feeder process, the input is the molten glass stream coming from the furnace into the feeder system. The output is the gob of glass, which is later formed into a glass container. In this study, the incoming glass flow is heated from the top of glass flow by gas burners. There are five of these heating zones from input to

output. At the final zone, there are nine temperature measurements arranged in three different heights and widths of the flow for controlling the homogeneity of the temperatures.

As the first step, the flexibility potential was identified to be in the thermal capacity of the glass. At certain times, the glass flow can be heated or left to cool while still retaining the temperature homogeneity target at the final zone.

Second step is to create the optimization model. The cost function (eq 1.) minimizes the energy consumption via gas consumption and the glass heterogeneity in the final zone for the whole time horizon.

$$\min w_1 \cdot \sum_{\substack{z \in Z \\ k \in K}} c_k g_{z,k} + w_2 \cdot \sum_{\substack{i,j \in \{1,2,3\} \\ k \in K \\ z \in S}} \frac{V_k + H_k}{\max(T_{k,z_f})} \quad (1)$$

where g is the decision variable, representing the gas openings for each heating zone. c is the cost vector that defines the cost of energy usage for each time step k . Second term minimizes the temperature differences in vertical V and horizontal H directions in the final zone z .

The heat transfer equations that define the main optimization problem constraints can be formulated as in (eq 2.)

$$\text{s.t. } T_{i,j,z}(k+1) = T_{i,j,z}(k) + \bar{\alpha}_{i,j,z} \cdot \Delta \bar{T}_{i,j,k}, \\ \forall i \in I, \forall j \in J, \forall z \in Z \quad (2)$$

where α -vector includes all the heat transfer coefficients for the element i,k,z and $\Delta \bar{T}$ -vector has all the corresponding temperature differences for that element. By changing the weights in the cost vector c , the model quantifies the flexibility potential in the process.

The model is constructed as 3x3x5 uniform temperature glass volume elements. Each element is modeled as a plug flow with ideal mixing. Heat transfer equations for convection, conduction, and advection are written as constraints of the optimization problem represented with matrix A . There are constraints for each of the six sides of every volume for every time step in the whole optimization horizon. Other constraints are the allowed maximum and minimum temperatures for each volume.

In the fourth step the cost for energy usage is varied and the corresponding flexibility potentials are recorded and sent for validation. The suggested gas openings are then validated first in an accurate computational fluid dynamics model for the process and then in the real process.

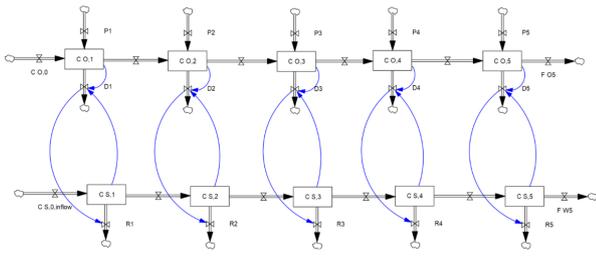


Fig. 1. Aeration process formulation with two parallel flows. Upper flow is the oxygen flow and the lower flow is the organic material.

3.2 Aeration process flexibility quantification

The wastewater treatment plant that this framework was tested on uses the prevalent active sludge process to remove the organic material of septic sewage and municipal wastewater. As the aeration process is the main consumer of energy in this plant, it was chosen as the best subprocess to test the designed framework on. In the aeration tank, the incoming sewage and wastewater from the primary sedimentation flows through lanes one to five, before exiting into secondary sedimentation. On every lane there is a group of mechanical aerators that increase the amount of dissolved oxygen which the bacteria in the active sludge needs in turn to consume the organic material in the wastewater.

The identified flexibility source needed in step one is here the overcapacity of the aerators, since they do not have to be used at maximum power at all times. The average hydraulic retention time is approximately 20 hours so there is a possibility to delay the aeration into the later lanes while still retaining the target concentration of biochemical oxygen demand (BOD).

In the second step of the framework the optimization model of the aeration process was formulated. This was done as two parallel mass flows of organic material and dissolved oxygen that affect each other as seen in (kuva). The underlying flow of active sludge, that is recirculated into the aeration tank from the bottom of secondary sedimentation, was approximated out of the optimization model to increase the calculation speed. This approximation was based on the tight DO constraints in each lane which should assure that the critical amount of active sludge will remain in the process at all times.

The objective function minimizes the combined aerator usage over the time horizon of next N hours as seen

in (eq. 3)

$$\min \sum_{i=1}^N c_k \cdot x_k \quad (3)$$

where c is the cost vector of each time step k of energy usage. x is the decision variable for combined usage of all aerators in the tank. Optimization is constrained by the mass flow equations for sewage and oxygen concentrations and hard limits for DO concentration and BOD output from the tank.

Cost vector in the (eq. 3) is then used in the third step of the framework to calculate the energy flexibility potentials from the process as explained. The calculated results are then validated from non-linear active sludge model (ASM1) based simulator before deployment and integration.

Acknowledgement

This project has received funding from the European Union’s Horizon EUROPE research and innovation programme under Grant Agreement No 101058174 “TRINEFLEX”.

References

- [1] Kanerva A. Defining Energy Flexibility for Energy-intensive Industrial Processes. 2025. Extended abstract for Automaatiopäivät 2025.
- [2] Ranta A. Comparison of Integration Architectures for Process Flexibility in Industrial Processes. 2025. Extended abstract for Automaatiopäivät 2025.

Heikki Hyyti*, Petri Manninen, and Jyri Maanpää

ROADVIEW: Perception for Autonomous Vehicles in Adverse Weather Conditions

Abstract: ROADVIEW is an EU-funded Horizon Europe Innovation Action aiming to develop robust and cost-efficient in-vehicle perception and decision-making systems for connected and automated vehicles with enhanced performance under harsh weather conditions and different traffic scenarios. In ROADVIEW, researchers from Finnish Geospatial Research Institute FGI develop two novel perception methods: 1) Environment-aware high-definition mapping method for real-time positioning of an autonomous vehicle, and 2) Optical measurement of road grip and road surface conditions in front of the vehicle.

Keywords: autonomous driving, road surface, lidar, machine vision, positioning

1 Background

Autonomous vehicles require an accurate position and orientation to operate safely. Inertial assisted satellite navigation systems that combine global navigation satellite system (GNSS) and inertial measurements (INS) can provide accurate position and orientation estimates in good conditions. However, relying solely on one positioning solution makes the system vulnerable to malicious agents, e.g. satellite signals can be subject to jamming or spoofing [1] and they the visibility of satellites may be limited (e.g. in forest [2], tunnels or urban canyons [3]). On the other hand, the inertial estimates drifts because of errors accumulated from noisy and biased inertial measurements. Therefore, an alternative solution is preferred. We propose that a prebuilt map can provide accurate absolute position and orientation independent of satellite systems.

***Corresponding author: Heikki Hyyti**, Finnish Geospatial Research Institute FGI, National Land Survey of Finland, E-mail: heikki.hyyti@nls.fi

Petri Manninen, Finnish Geospatial Research Institute FGI, National Land Survey of Finland, E-mail: petri.manninen@nls.fi

Jyri Maanpää, Finnish Geospatial Research Institute FGI, National Land Survey of Finland, E-mail: jyri.maanpaa@nls.fi

Co-funded by the European Union. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them. Project grant no. 101069576.

In arctic adverse weather conditions, although the vehicle would know its exact position, the driving conditions create a risk if the vehicle is not able to adjust its driving for changing conditions. The road slipperiness is challenging to estimate and not studied much [4]. The variable slipperiness of road surface, packed ice and snow on the road, and accumulated snow during snowfall need to be taken into account. Solving these is essential to allow automated vehicles to operate safely also in difficult weather conditions common in northern countries. Solutions to these challenges are studied and demonstrated in ROADVIEW [5].

2 Aims

The goal of our positioning development is to provide a map representation, automatically made from laser scanned point clouds, that provides robust and accurate positioning while being memory efficient at the same time. Memory efficiency is crucial for mobile robots, such as autonomous vehicles, due to the limited on-board storage capacity and the limited bandwidth of wireless connection.

The goal of road grip and road surface conditions estimation is to improve safety of autonomous driving in challenging weather conditions. By providing a novel capability of estimating the road surface conditions before driving over the road allows the vehicle to adjust its velocity and control behaviors to take into account low-grip conditions or uneven icy surface in front of the vehicle.

3 Materials and Methods

The HD Map representation developed in ROADVIEW project is based on a registering technique called Normal Distributions Transforms (NDT) which models the dense point clouds produced with lidar sensors as sets of 3D normal distributions to compress the information. By using the NDT, we are able to use existing point cloud registration methods with our map, but at the same time we utilize information from semantic segmentation to define which points should be used in the map and how the points should be divided into distributions. We call our method Environment-Aware NDT or EA-NDT [6]. An example of EA-NDT map with 3D distributions is shown in Fig. 1

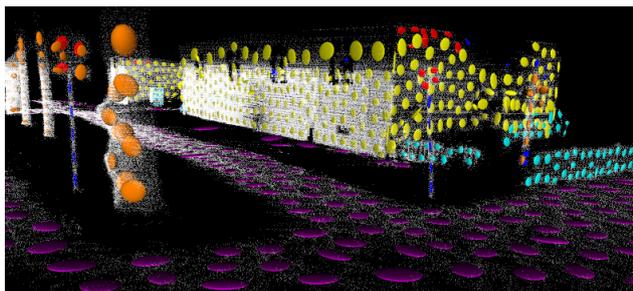


Fig. 1: An illustration of EA-NDT HD map representing the original point cloud (white). The 3D distributions are visualized as ellipsoids (mass within a standard deviation), semantic information is shown with colors: building (yellow), fence (cyan), ground (purple), pole (blue), tree trunk (orange) and traffic sign (red) labels.

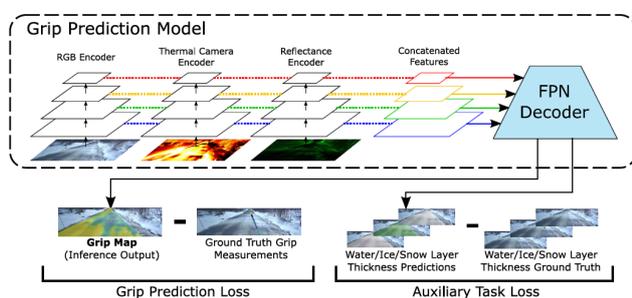


Fig. 2: In the model architecture each input data modality has a separate encoder and their features are concatenated within each feature scale before the FPN decoder. The loss is evaluated both for the grip and the auxiliary surface layer thickness prediction tasks simultaneously. See more details in [7].

The road surface grip estimation is based on a deep-learning solution using a Feature Pyramid Network (FPN) (see Fig. 2) The method fuses lidar, thermal camera, and color camera data streams and predicts road grip as well as, water, snow, and ice layer thicknesses [7]. It is the first real-time capable method providing a dense road grip estimate from the road surface.

4 Results

In [6], we have shown that the developed EA-NDT HD map representation can provide $1.5\times$ higher descriptivity with the same amount of data than the traditional NDT which means that the same accuracy can be achieved with less data. In ROADVIEW deliverable [8], we have shown that the accuracy of positioning with EA-NDT is very similar compared to the original NDT but with less data.

Our recently published article [7] demonstrated how road grip can be estimated by fusing lidar with thermal

and color camera information. The method has been successfully used to predict road grip from the sensor fused input with root mean square errors (RMSE) of less than 0.06 (from the unit-less friction values ranging between 0.1 and 0.82).

5 Conclusions

In this work we highlighted the importance of research and development done in ROADVIEW[5] and the perception related research by Finnish Geospatial Research Institute (FGI) for the project to allow safer automated traffic in adverse weather conditions common in northern countries. In this work we showed how automated vehicles could in future position themselves using point cloud producing lidar sensors and high-definition maps and better take the road surface properties into account in their driving.

References

- [1] K. Radoš, M. Brkić, and D. Begušić, "Recent advances on jamming and spoofing detection in GNSS," *Sensors*, vol. 24, no. 13, p. 4210, 2024.
- [2] H. Kaartinen, J. Hyyppä, M. Vastaranta, A. Kukko, A. Jaakkola, X. Yu, J. Pyörälä, X. Liang, J. Liu, Y. Wang *et al.*, "Accuracy of kinematic positioning using global satellite navigation systems under forest canopies," *Forests*, vol. 6, no. 9, pp. 3218–3236, 2015.
- [3] D. Egea-Roca, M. Arizabaleta-Diez, T. Pany, F. Antreich, J. A. Lopez-Salcedo, M. Paonni, and G. Seco-Granados, "GNSS user technology: State-of-the-art and future trends," *IEEE Access*, vol. 10, pp. 39 939–39 968, 2022.
- [4] A.-P. Botezatu, A. Burlacu, and C. Orhei, "A review of deep learning advancements in road analysis for autonomous driving," *Applied Sciences*, vol. 14, no. 11, p. 4705, 2024.
- [5] Acceloment Schweiz AG. (2024) ROADVIEW. Accessed: 15.1.2025. [Online]. Available: <https://roadview-project.eu>
- [6] P. Manninen, H. Hyyti, V. Kyrki, J. Maanpää, J. Taher, and J. Hyyppä, "Towards high-definition maps: A framework leveraging semantic segmentation to improve NDT map compression and descriptivity," in *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2022, pp. 5370–5377.
- [7] J. Maanpää, J. Pesonen, H. Hyyti, I. Melekhov, J. Kannala, P. Manninen, A. Kukko, and J. Hyyppä, "Dense road surface grip map prediction from multimodal image data," in *International Conference on Pattern Recognition*. Springer, 2025, pp. 387–404.
- [8] P. Manninen, T. Kivioja, and H. Hyyti, "SW on improved localization using high-density map updating – first report," European Commission, Deliverable 5.6, 2024, project no. 101069576. [Online]. Available: <https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e50cbfc960&appId=PPGMS>

Markku Ohenoja*, Samuli Bergman, Outi Rask ja Yrjö Majanne

Automaatio vihreässä siirtymässä -kysely ja työryhmän toimintasuunnitelma

Tiivistelmä: Automaatioteknologian ja -osaamisen merkitys vihreässä siirtymässä on merkittävä. Tätä seikkaa ei kuitenkaan aina tunnisteta vihreästä siirtymästä keskustellessa. Suomen Automaatioseura ry perusti työryhmän suunnittelemaan teemaan liittyviä tapahtumia, jotta automaation rooli saa ansaitsemansa näkyvyyden. Tämä esitys keskittyy kertomaan jäsenistölle suunnatun kyselyn perusteella tehdyistä havainnoista sekä työryhmän tulevista aktiviteeteista.

Asiasanat: automaatio, vihreä siirtymä, työryhmätyöskentely, toimintasuunnitelma, kyselytutkimus

***Vastaava kirjoittaja: Markku Ohenoja:** Oulun yliopisto, E-mail: markku.ohenoja@oulu.fi

1 Johdanto

Suomen Automaatioseura ry järjesti keväällä 2023 Automaatiopäivät teemalla ”Automaatio ja koneoppiminen vihreän siirtymän mahdollistajina”. Suomen Automaatioseura näkee, että automaatiolla on merkittävä, mutta hieman näkymättömissä oleva rooli vihreässä siirtymässä ja perustikin määräaikaisesti toimivan työryhmän teemaan liittyen. Työryhmä aloitti toimintansa marraskuussa 2023 ja sen keskeisimmäksi tehtäväksi määriteltiin aiheeseen liittyvän tiedon koonti ja soveltuvan foorumin perustaminen.

Yleisesti ottaen automaatioalan merkitys vihreässä siirtymässä korostuu mm. teollisuusprosessien energiankäytön ja materiaalitehokkuuden optimoinnissa, uusiutuvien energialähteiden joustavassa integroinnissa sähköverkkoihin, älykkäiden liikennejärjestelmien kehittämisessä sekä data-analytiikassa ja tekoälyratkaisuihin eri sektoreilla. Halusimme kuulla lisää jäsenistömme ja sidosryhmiemme ajatuksista ja laadimme kyselyn, jonka vastausten perusteella pystyisimme parhaalla mahdollisella tavalla ohjata toimintaamme automaation roolin esille nostamisessa vihreässä siirtymässä.

2 Kyselyn toteutus

Kysely kohdennettiin jäsenistölle alun perin sähköpostilistan kautta, mutta sitä sai myös jakaa yhdistyksen ulkopuolelle. Kysely oli avoinna 8.11.-16.12.2024. Vastauksia kertyi lopulta 18 kappaletta. Vastaajista yhdeksän oli seuran jäseniä ja yhdeksän seuraan kuulumattomia.

Kyselyssä oli yhdeksän pisteytettävää kysymystä (täysin eri mieltä = 1, täysin samaan mieltä = 5) liittyen tietoisuuteen vihreästä siirtymästä, automaation roolista osana vihreää siirtymää ja vastaajan omasta roolista tässä megatrendissä. Seuraavat yhdeksän pisteytettävää kysymystä liittyivät Suomen Automaatioseuran rooliin ja aktiviteetteihin tämän teeman ympärillä.

Avoimissa kysymyksissä tiedusteltiin tarkemmin vastaajien näkemystä, että millaisia teemoja olisi syytä tuoda esiin seuran järjestämissä tapahtumissa ja mitkä sidosryhmät voisivat olla tärkeitä liittää keskusteluun. Lisäksi vastaajilla oli mahdollisuus kertoa muita mietteitä teemaan liittyen.

Yhdistystoiminnan ja työryhmien vapaaehtoisen luonteen vuoksi käytimme samassa yhteydessä myös mahdollisuuden kartoittaa potentiaalisia aktiivisia toimijoita tämän asian parissa. Kyselyn viimeinen osa käsittelikin vastaajan halukkuutta osallistua Suomen Automaatioseuran vihreän siirtymän teemaan liittyviin tapahtumien järjestelyihin.

3 Tulokset ja jatkotoimenpiteet

Vastaajista peräti 39 % oli kiinnostuneita osallistumaan Automaatio vihreässä siirtymässä -teeman tapahtumien järjestelyyn. Muutoinkin avoimet vastaukset antoivat arvokasta näkemystä ja ideoita, miten työryhmä voisi jatkaa työtään. Neljä vastaajaa toivoi myös erillistä yhteydenottoa työryhmältä.

Taulukossa 1 on esitetty kyselyn tulosten keskiarvot sekä hajonnat. Vastaajat tiesivät hyvin, mitä vihreä siirtymä (VS) tarkoittaa ja useimmat kokivat olevansa osallisena ja pitivät itseään vihreän siirtymän osajana.

Tosin kysymyksissä, jotka koskivat henkilökohtaista osallisuutta ja osaamista vihreässä siirtymässä, vastaajien mielipiteet vaihtelevat eniten.

Parhaiten yksimielisiä vastaajat olivat kysymyksissä, jotka koskevat automaation roolia ja merkitystä vihreässä siirtymässä. Automaation roolin kasvattaminen ja sen näkyväksi tekeminen olivat kyselyn keskeisiä teemoja, joissa vastaajat olivat myös vahvasti samaa mieltä. Tämä vahvistaa myös työryhmän toiminnan tarpeellisuutta ja motivoi jatkamaan työtä sekä jalkauttamaan tekemistämme tapahtumien tasolle.

Automaatioseuran roolin vastaajat näkivät nimenomaan linkkinä eri sidosryhmien välillä. Avoimissa vastauksissa muistuteltiin vihreän siirtymän olevan yksi megatrendi muiden ohessa, joten ei tule unohtaa automaation kokonaisvaltaista tärkeyttä teknisesti, taloudellisesti ja yhteiskunnallisesti. Seuran ei tulisi tai olisi kovin järkevää rajallisilla resursseillaan panostaa varsinaisten kehityshankkeiden käynnistämiseen.

Taulukko 1. Pisteytettävien kysymysten tulokset.

Kysymys	KA	σ
Tiedän, mitä vihreä siirtymä tarkoittaa	4.45	0.67
Olen osallisena vihreässä siirtymässä	3.14	1.28
Olen mielestäni vihreän siirtymän osaaja	3.55	1.10
Vihreä siirtymä kasvattaa automaation roolia ja merkitystä teollisuudessa ja liiketoiminnassa	4.55	0.51
Automaatiotoimijat ovat vahvasti mukana VS:ään liittyvissä TK-hankkeissa	3.82	1.10
Automaatiotoimijat ovat vahvasti mukana vihreän siirtymän yrityksissä	3.55	0.74
Automaation ratkaisut ovat välttämättömiä vihreän siirtymän toteuttamiseksi	3.18	0.73
VS kasvattaa automaatioalan yritysten liikevaihtoa seuraavan 2 v. aikana	4	0.87
VS kasvattaa automaatioalan yritysten tuottavuutta ja liikevoittoa seur. 2 v. aikana	4.77	1.14
Webinaareja	3.91	0.63
Seminaareja	3.91	0.80
Paneelikeskusteluja	3.05	1.10
Toimia linkkinä automaation osaajien ja muiden vihreän siirtymän toimijoiden välillä	4	1.14
Toimia linkkinä automaatioalan yritysten, tutkimuslaitosten ja korkeakoulujen välillä	4.77	1.11
Tukea suomalaisen VS:ään liittyvän automaatio-osaamisen kansainvälistymistä	3.91	1.11
Käynnistää kehityshankkeita	3.05	0.95
Pyrkiä mukaan olemassa oleviin vihreän siirtymän ohjelmiin ja foorumeihin	4	0.93
Tehdä automaation roolia vihreässä siirtymässä näkyväksi	4.77	0.53

Tapahtumien osalta erityisesti webinaarit saivat kannatusta kaikilta vastaajilta. Avoimissa vastauksissa

esille nousivat substanssin korostaminen, huoli tulevaisuuden osaajien tarpeesta ja alan koulutuksesta sekä standardoinnin hidastuminen. Konkreettisia aihe-ehdotuksia tapahtumiin olivatkin mm.

- Miten automaatio varmistaa vihreän siirtymisen turvallisuuden ja onnistumisen? Miten hajauttaminen asiakasrajapintaan asti onnistuu ja ekosysteeminäkökulman tunnettavuutta parannetaan (standardointi, rajapinnat, toiminnallisuudet, tietoturva, turvallisuus)?
- Koulutus ja osaamisen kehittäminen esimerkiksi tehoelektronikan säätöratkaisuisissa, kysyntäjoukon toteuttamisessa, sähköverkon stabiilisuuden varmistamisessa sekä tiedonkeruun, data-analytiikan ja tekoälyn hyödyntämisessä.
- Mikä erottaa vihreän siirtymän projektit muista projekteista liiketoiminnan näkökulmasta katsottuna?
- Vihreän siirtymän merkitys Suomessa nykyisin toimiviin ja toimintaansa aloittaviin laitoksiin ja teollisuuden aloihin.

Sidosryhmien osalta vastauksissa esiin nousivat tutkimuslaitosten ja automaatioalan yritysten lisäksi standardointiorganisaatiot, regulaation parissa toimivat tahot sekä klusteritoiminta. Huomiota voisi kiinnittää myös vähemmän tavanomaisiin toimijoihin, kuten sektoritutkimuslaitoksiin tekniikan alan ulkopuolella sekä energia-alaan ja kiertotalouteen liittyviin yrityksiin. Työryhmä onkin jo aiemmin määritelty yhdeksi haasteeksi automaatioalan merkityksen ja äänen esille tuonnin klusteritoiminnan yhteydessä, ei-teknille organisaatioille sekä maakunnallisille ja alueellisille toimijoille. Tämä vaatii mm. viestinnän suoraviivaistamista ja verkostoitumista tavanomaisuudesta poikkeavilla tavoilla.

Työryhmän muut tavoitteet liittyvät mm. asiantuntijoiden sitouttamiseen työryhmätyöhön ydinryhmän lisäksi sekä kohderyhmien kartoitus Automaatioseuran ja vihreän siirtymän alalla jo toimivien foorumeiden lisäksi. Jälkimmäinen voisi kohdentua myös tulevaisuuttaan miettiviiin nuoriin.

Toteutetun kyselyn jälkeen työryhmä suunnittelee nyt toteuttavansa webinaarisarjan kevään ja kesän 2025 aikana, jossa keskitytään kyselyssä esille nousseisiin teemoihin. Webinaarien sisällöstä pyritään tuottamaan myös artikkeleita Automaatioväylään ja hyödyntämään näitä materiaaleja muillakin foorumeilla. Työryhmän visiossa on myös toteuttaa vihreää siirtymää tukevien konkreettisten automaatiotratkaisujen ja menestystarinoiden esittelyä syksyn 2025 Teknologia -messuilla osana Suomen Automaatioseuran ohjelmaa.

Fredrik Hellman*, Janne Hakala, William Antus, André Norrback, Andreas Lundell, and Jerker Björkqvist

Automated Life Cycle Assessment in Scalable and Flexible Manufacturing

Abstract: Traditional Life Cycle Assessment (LCA) processes are time-consuming and rely heavily on manual input. In collaboration with Mirka, a Finnish manufacturing company producing abrasives, we integrate real-time data flows between production databases and LCA tools. This collaboration is ideal due to Mirka's extensive product portfolio, containing thousands of different products, providing a strong foundation for demonstrating the scalability and versatility of the automated LCA framework. We utilize a data lakehouse architecture to enable seamless handling of diverse datasets often required for LCA and supports near real-time updates to sustainability metrics. This automated solution minimizes manual effort, adapts dynamically to operational data changes, and delivers a continuous overview of environmental performance.

Keywords: Life Cycle Assessment, Data Lakehouse, Real-time Data Integration, Automated LCA, Manufacturing

***Corresponding Author: Fredrik Hellman:** Åbo Akademi University, E-mail: fredrik.hellman@abo.fi

Janne Hakala: Åbo Akademi University, E-mail: janne.hakala@abo.fi

William Antus: Mirka Ltd, E-mail: william.antus@mirka.com

André Norrback: Mirka Ltd, E-mail: andre.norrback@mirka.com

Andreas Lundell: Åbo Akademi University, E-mail: andreas.lundell@abo.fi

Jerker Björkqvist: Åbo Akademi University, E-mail: jerker.bjorkqvist@abo.fi

1 Introduction

Life Cycle Assessment (LCA) evaluates the environmental impacts of a product throughout its entire life cycle. LCA plays a key role in driving sustainability, supporting frameworks like Environmental Product Declarations (EPDs) and Digital Product Passports (DPPs), both essential for complying with circular economy (CE) principles. Yet, traditional LCA methods remain manual, time-consuming, and static, [1] which limits their usefulness for current sustainability needs. With the European Union's Corporate Sustainability Reporting Di-

rective (CSRD) requiring transparent reporting on sustainability, [2] companies are pushed towards more sustainable production, and could benefit from implementing more dynamic and automated processes in calculating sustainability metrics.

For companies with extensive product portfolios, often containing over thousands of products, automation is essential to make the LCA process more effective. Additionally, automating LCA calculations unlocks further benefits, such as real-time visualization of emissions during production, supporting data-driven management and continuous performance monitoring.

In this study, we implement an automated life cycle assessment (ALCA) process at Mirka. The goal is to demonstrate how automating LCA calculations can reduce manual effort and enhance the scalability of sustainability assessments. By leveraging a data lakehouse architecture, we enable near real-time integration of production data with LCA tools, allowing for dynamic updates to sustainability calculations. This approach could improve efficiency and provide Mirka with continuous insights into environmental performance, promoting data-driven decision-making for more sustainable production.

2 Background

2.1 Automated Life Cycle Assessment

The main challenge for automated LCA for complex products are defined by [3] as the conflict of objectives between accuracy and efficiency, the manual workload for mapping input data against life cycle inventory (LCI) datasets, the lack of flexibility in LCI modelling, and the missing application in commercial LCA software.

There is currently no framework supporting fully automated LCA calculations. However, commercial LCA software solutions, such as SimaPro Synergy [4], and Sphera [5], have recently released application programming interfaces (APIs), enabling programmatic communication with their systems, underlining the need

for automated solutions in industry. Additionally, the framework proposed by [1] presents an ALCA process for manufacturing companies, and [3] solved their defined challenges by developing an LCI modeling approach, allowing automated assignments of a component's attributes to pre-defined LCI models using commercial LCA tools, indicating that research efforts are also in progress.

2.2 Mirka Ltd

Mirka is an essential partner for this project due to several key factors. First, their broad product portfolio provides the perfect test case for demonstrating the scalability of the ALCA framework. With thousands of distinct products, the system can be tested for its ability to handle diverse materials, processes, and environmental impacts at scale.

Second, Mirka's established data infrastructure supports integration capabilities with real-time LCA tools. Their existing systems ensure that the automated framework can access reliable and well-organized data for seamless processing. Additionally, Mirka's strong sustainability focus, including initiatives like transitioning to fossil-free electricity and reducing emissions, shows willingness to adapt to sustainability efforts.

This combination of complexity, data readiness, and sustainability alignment makes Mirka an ideal collaborator for implementing and showcasing the ALCA system.

3 Aims

The aim with this study is to implement an ALCA process that integrates real-time production data into LCA tools, validate the scalability and flexibility of the ALCA framework by applying it to Mirka's extensive product portfolio, and demonstrate continuous sustainability monitoring through real-time visualizations of key environmental indicators.

4 Methods

The ALCA workflow implemented in this study is illustrated in Figure 1. The ALCA framework at Mirka integrates real-time data from ERP, MES, and sensor systems into a centralized data lakehouse, acting

as a storage repository, to enable automated, dynamic LCA updates. Python scripts process and map data to OpenLCA models, with results like carbon emissions fed back into the storage repository to be used in for example dashboards for near real-time monitoring. The system supports version control for traceability and will be tested for scalability and performance across Mirka's products.

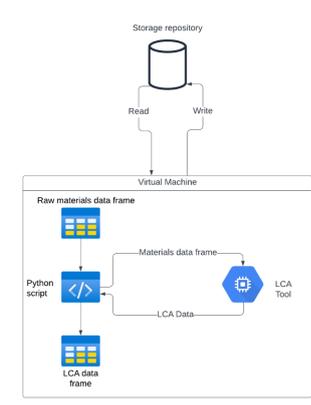


Fig. 1. ALCA Workflow

References

- [1] Schneider D, Jordan P, Dietz J, Zaeh MF, Reinhart G. Concept for Automated LCA of Manufacturing Processes. *Procedia CIRP*. 2023;116:59–64. URL <https://www.sciencedirect.com/science/article/pii/S2212827123000161>
- [2] European Commission. Directive (EU) 2022/2464 of the European Parliament and of the Council on Corporate Sustainability Reporting (CSRD). *Tech. Rep. L 322/15*, Official Journal of the European Union. 2022. Accessed: January 30, 2025. URL <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022L2464>
- [3] Haun P, Müller P, Traverso M. Improving automated Life Cycle Assessment with Life Cycle Inventory model constructs. *Journal of Cleaner Production*. 2022;370:133452. URL <https://www.sciencedirect.com/science/article/pii/S0959652622030347>
- [4] SimaPro. SimaPro Synergy: Collaboration and Data Sharing for LCA. <https://simapro.com/synergy/>. n.d. Accessed: January 30, 2025.
- [5] Solutions S. LCA Automation: Life Cycle Assessment Software and Data. <https://sphera.com/solutions/product-stewardship/life-cycle-assessment-software-and-data/lca-automation/>. n.d. Accessed: January 30, 2025.

Taneli Lohi*, Samuli Soutukorva and Tapio Heikkilä

Programming of Skill-based Robots

Abstract: Manufacturing is facing constantly changing market demands, with faster innovation cycles resulting in growing agility and flexibility requirements. Industry 4.0 has been transforming the manufacturing world towards digital automation and the importance of software has increased drastically. Easy and fast task programming and execution in robot-sensor systems become a prerequisite for agile and flexible automation and in this paper, we propose such a system. Our solution relies on a robot skill library, which provides the user with high-level and parametrized operations, i.e., robot skills, for task programming and execution. Programming actions result in a control recipe in a neutral product context and is based on use of product CAD models. Practical tests are also reported to show the feasibility of our approach.

Keywords: robot programming, robot skill, computer vision

***Corresponding Author: Taneli Lohi:** VTT Technical Research Centre of Finland, E-mail: taneli.lohi@vtt.fi

Samuli Soutukorva: VTT Technical Research Centre of Finland, E-mail: samuli.soutukorva@vtt.fi

Tapio Heikkilä: VTT Technical Research Centre of Finland, E-mail: tapio.heikkila@vtt.fi

1 Introduction

Automation in agile and very flexible manufacturing, where lot sizes go at the extreme cases down to one is very demanding, because the set-up and execution of new tasks should be nearly instant. This implies reduced integration effort and easy reuse of available devices and software on the production lines. The devices must offer a uniform interface to fulfil flexibility requirements and new devices and components of a production line must be integrated fast and easy, independent of the component's manufacturer [1]. Software plays a key role, and the transition to small batches implies robot software structures and control architectures that can provide the basis for the required flexibility [2].

Our approach to solve the challenges of agile and flexible robot automation is to introduce a system for easy programming and execution of robot tasks. Our solution relies on an executable robot skill library, which provides the user with high level parametrized robot skills. Programming is based on use of product CAD models in a neutral format and is carried out using a planning and programming software in the product context, focusing on what operations, i.e., robot skills, need to be carried out to accomplish the required changes in the relations and properties of parts. We have developed a planning and programming software system as well as a robot skill library, with which task sequences and all detailed parameters can be easily programmed into a control recipe. The control recipe is interpreted by the control software and skills and operations are allocated to available resources and executed in a robot cell.

Our main contribution and novelty is in providing the method and software implementation for easy task planning and programming in the product context based on CAD models – as well as in the modelling of synchronization of skills.

2 Hierarchical control – modelling tasks, skills and primitives

Our control architecture follows the principles of the common three-layer architecture [3]. We have layers for tasks, skills, and primitive operations. Parametrized skills and primitives are specified, designed, implemented, and tested and realized as a reusable component library, relying on which, varying tasks can be planned and programmed. Tasks are formulated as sequences of skills, which further on are decomposed according to the behaviour patterns of the skills and primitives. In principle, tasks have no predefined control structures, but are always composed as a sequence of skills, specified by human operator or programmer.

Skills and primitives have always their predefined sequence control structures, including synchronization of skills and primitives. Planning a task is done by the user by selecting skills one by one from a list of skills and setting a target object for each skill. Further on, the required parameters for skills are derived from the CAD models of the parts connected to the skill. A complete

task plan with the skill sequence and related skill parameters is finally composed into a control recipe, which is forwarded to the robot control system. The robot control system merges configuration data of the robot system to finalize the skill and primitive parameters.

Each control sequence of a skill or a primitive operation is implemented as a control program component: as an executable, as a module in an executable or as a module in an interpreted control script. Task level control is implemented with an interpreter in the python language, which parses the control recipe and triggers skill controls in the order specified in the control recipe. The control recipe is implemented as a JSON file, which is passed from the planning software to the runtime environment of the task control. Robot cell configuration data is implemented currently embedded in the configuration files of the HW and SW components, or embedded, as global variables in the interpreter programs

3 Planning and programming system for tasks and skills

A CAD based programming system has been developed using the geometric engine of the OpenCascade Technology [4]. The operator creates a task by selecting predefined skills from list and adding them to the skill sequence. Each skill is connected to one or more target object to be manipulated during skill execution. Geometric features of the target object are used to derive parameters for each skill.

Currently available skills that are supported by the task planning system, are Pick, Place, Localize object, Scan, Pick localized, Place localized and Scan localized. The skills are written to a task recipe, that contains the skills in execution order and the needed parameters for executing each skill.

4 Experimental system and testing

The task programming and control methods were implemented in our laboratory test facilities. The CAD-based programming SW was implemented as a C++ executable. Task and skill controllers are implemented in the python language and skill controls are using VTT's 3D computer vision SW and 3D cameras. ROS Topic and Services based interface is used to communicate with computer vision SW and a robot controller. The robot controller is implemented in the used robot's programming language (KRL). Experimental system and skill models are presented in a more comprehensive way in [5].

An assembly task was created using a CAD model of the assembly by sequencing skills and attaching related parts to the skills interactively (figure 1, left). The skill sequence was written to STEP model. The skill sequence was read from the model and features that are used to generate parameters for each skill are selected from CAD model of the part (figure 1, right). Control recipes for the task was generated.

The assembly task was executed using the task control, with KUKA Agilus robot equipped with Schmalz suction gripper, and 3D computer vision system with Zivid 2 3D camera. (Figure 2)

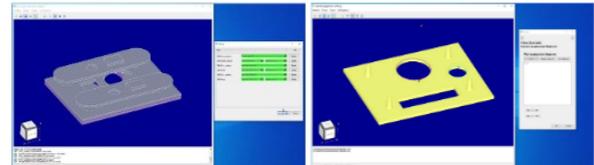


Figure 1. Creating a skill sequence and selecting features for skill parameter generation

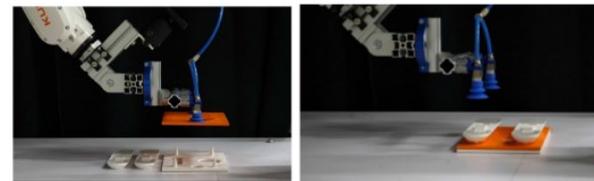


Figure 2. Execution of an assembly task

5 References

- [1] S. Profanter, A. Breitzkreuz, M. Rickert and A. Knoll, "A Hardware-Agnostic OPC UA Skill Model for Robot Manipulators and Tools," 2019 24th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), Zaragoza, Spain, 2019, pp. 1061-1068.
- [2] M. Mayr, F. Rovida and V. Krueger, "SkiROS2: A Skill-Based Robot Control Platform for ROS," 2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Detroit, MI, USA, 2023, pp. 6273-6280.
- [3] A. Ferrein, G. Lakemeyer, "Logic-based robot control in highly dynamic domains," Robotics and Autonomous Systems, Volume 56, Issue 11, 2008, Pages 980-991, ISSN 0921-8890.
- [4] OCCT Collaborative Development Portal. In: <https://dev.opencascade.org/> (2024-04-14) [19]
- [5] T. Lohi, S. Soutukorva and T. Heikkilä, "Programming of Skill-Based Robots," 2024 IEEE 19th Conference on Industrial Electronics and Applications (ICIEA), KIRSTIANSAND, Norway, 2024, pp. 1-7.

Harri Aaltonen*, Udayanto Dwi Atmojo ja Valeriy Vyatkin

Ilmastoinnin hyödyntäminen kysyntäjoustona risteilijäaluksilla

Abstrakti:

Risteilymatkailu on kasvanut maailmanlaajuisesti. Samalla kansainvälinen merenkulkujärjestö pyrkii merenkulkuun liittyvien kasvihuonepäästöjen vähentämiseen. Laivoilla moottoreita käynnistetään tuottamaan tarvittu määrä energiaa. Liian alhaista energian tuotantoa suhteessa kulutukseen voidaan tarvittaessa kompensoida myös kysyntäjouston avulla. Propulsion jälkeen laivalla suurin energiankulutus syntyy ilmastoinnista. Ilmastoinnilla on osoitettu olevan potentiaalia toimia kysyntäjoustossa johtuen kuorman helposta ohjattavuudesta ja ilmastointijärjestelmän dynamiikan hitaudesta. Tässä artikkelissa käsitellään keskeneneräistä tutkimusta ilmastoinnin käyttämisestä kysyntäjoustossa laivoilla ja siihen liittyviä haasteita. Tutkimusmenetelmänä käytetään APROS-simulointimallia laivan ilmastointijärjestelmästä ja vahvistusoppimista.

Asiasanat: Ilmastointi, Kysyntäjousto, vahvistusoppiminen

***Harri Aaltonen:** Aalto-yliopisto, E-mail: harri.aaltonen@aalto.fi

Udayanto Dwi Atmojo: Aalto-yliopisto, E-mail: udayanto.atmojo@aalto.fi

Valeriy Vyatkin: Aalto-yliopisto & Luulajan teknillinen yliopisto, Email: valeriy.vyatkin@aalto.fi

1 Johdanto

Kansainvälinen merenkulkujärjestö pyrkii seuravan 25 vuoden aikana saamaan meriliikenteen hiilineutraaliksi. Laivojen elinkaari on noin 25–30 vuotta, minkä vuoksi energiankäytön optimointi koskee myös nykyisiä aluksia. Energiantuotannon ja kulutuksen tulee olla yhtä suurta jokaisena ajanhetkenä. Maissa liian alhaista energian tuotantoa suhteessa kulutukseen voidaan kompensoida ostamalla sähköä naapurimaista. Tällainen markkinaehtoinen lisäkapasiteetti ei kuitenkaan ole mahdollinen laivoilla. Kulutusjouston käyttö lisää energijärjestelmän joustavuutta.

Laivoilla energia tuotetaan keskitetysti. Risteilyaluksilla yleisin tapa on tuottaa sähköä diesel-, maakaasu- tai hybridi moottorien avulla [1]. Aluksen sähkönkäyttö on optimaalista silloin, kun energiankulutus vastaa moottorien optimaalisella käyntialueella tuottamaa määrää [2]. Laivojen energiaoptimointi on liiketoimintapäätös, jolloin optimaalinen nopeus energiankulutuksen näkökulmasta [1] ei aina ole liiketoiminnan kannalta optimoitua [3]. Samalla tavalla risteilijäaluksilla kulutusjouston käyttäminen on aina liiketoimintapäätös, jossa halutaan löytää optimaalinen tila kahden, usein ristiriitaisen, tavoitteen välillä. Yksinkertaisin kulutusjoustomenetelmä laivoilla on säätää laivan nopeutta [2]. Lähestyttäessä satamaa, laiva hidastaa vauhtiaan, jolloin energiantarve vähenee ja moottoreita voidaan sammuttaa. Samalla nopeuteen liittyvä kulutusjoustopotentiaali vähenee aikataulupaineen myötä. Tällöin kulutusjousto on mahdollista hakea risteilijäaluksilla hotellitoiminnoista. Hotellitoimintojen energiankulutuksesta merkittävä osa johtuu ilmastoinnista. Ilmastointi on potentiaalinen kysyntäjouston instrumentti risteilijäaluksilla, johtuen ilmastoinnin energiankulutuksen määrästä, ohjattavuudesta ja ilmastoinnin dynamiikan hitaudesta [4].

Ilmastoinnissa erityisesti kylmän tuottaminen vaatii paljon energiaa. Laivoissa kylmävesiasemat palvelevat keskitetysti koko laivan jäähdytystarvetta. Tällöin energian säästö jäähdytyksestä vaikuttaa koko laivaan. Ilmanvaihtoon liittyvien toimilaitteiden määrä mahdollistaa kulutusjouston aggregoimalla. Suuressa laivassa ilmanvaihtokoneita voi olla jopa sata ja yksittäinen hyttejä palveleva ilmanvaihtokone voi palvella noin sataa hyttiä. Ilmanvaihtokoneen ohella hytin ilmaa säädellään hyttikohtaisilla puhallinkonvektororeilla.

Ilmastoinnin energiankulutuksen joustaessa alaspäin, ilmanlaatu heikkenee. Energiankulutuksen mukaan, ilmastointia voidaan tehostaa ennen tarvetta kulutusjoustolle, jotta kulutusjouston kesto voidaan pidentää heikentämättä ilmanlaatua liikaa.

2 Tutkimusongelma

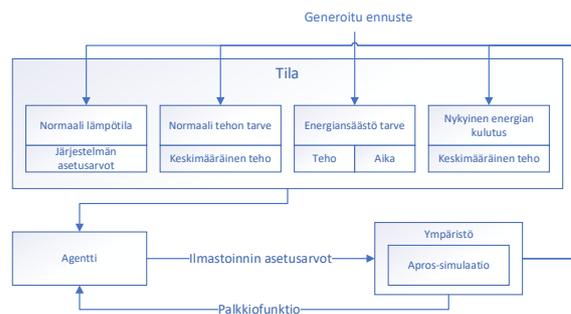
Tämän tutkimuksen tarkoituksena on selvittää, millainen joustopotentiali ilmastoinnilla on risteilijäaluksilla tehon ja ajallisen keston näkökulmasta. Tutkimuksen tutkimuskysymys on: Miten ilmastointia kannattaa ohjata holistisesti kulutusjoustopotentialin aikana? Tutkimuksen haasteena on, että energian kulutus on riippuvaista muun muassa hyttien ja ilmanvaihdon lämpötilojen asetusarvoista. Risteilijäaluksilla ilmastointi on pitkälle automatisoitu, jolloin yksittäisen asetusarvon muuttaminen ei usein ole riittävää kulutusjoustopotentialissa. Lisäksi, koska ilmastoinnissa hyödynnetään paljon poistoilman kierrätystä energiatehokkuuden lisäämiseksi, ei ilmastoinnin asetusarvojen muutokset ja niiden vaikutus energiankulutukseen määrään ja ilmanlaatuun ole intuitiivisesti ennustettavissa.

Tutkimuksen tavoitteena on vahvistusoppimista hyödyntäen luoda päätöksentekomalli, jossa riittävän tarkan ja validoidun simulointimallin avulla tekoälyä opetetaan tunnistamaan sellaiset ilmastoinnin asetusarvot, joiden avulla energian säästäminen on mahdollista ilman merkittäviä vaikutuksia ilmanlaatuun.

3 Menetelmät

Johtuen laivan ilmastoinnin kompleksisesta luonteesta, tutkimuksessa käytetään vahvistusoppimista. Vahvistusoppimisen on osoitettu olevan potentiaalinen ratkaisu kompleksissa ja epävarmuutta sisältävissä ympäristöissä.

Kuvassa 1 on ehdotus vahvistusoppimiseen tarvittavan järjestelmän yleiskuvasta. Opetettava agentti saa syötteenä yhden ilmastointikoneen viilennykseen ja lämmitykseen liittyvät lämpötilan asetusarvot sekä niiden hyttien lämpötilan asetusarvon, joita ilmastointikone palvelee. Lisäksi agentti saa tiedon ilmastoinnin vaatimasta keskimääräisestä tehonkulutuksesta, nykyisestä energiankulutuksesta sekä energiansäästöön liittyvän tarpeen tehonalenemalle ja kestolle. Näiden tietojen perusteella agentti opettelee tekemään päätökset hyttien ja ilmastointilaitteeseen liittyvistä lämpötilan asetusarvoista ja ilmastointikoneen puhaltimen kierrosluvusta.



Kuva 1: Järjestelmän yleiskuva

Ilmastointikoneen puhaltimella säädellään raittiin ilman määrää hytteissä. Hyttien oletetaan olevan vakioilmavirtajärjestelmiä, jolloin niihin ei yleensä aseteta CO_2 antureita. Tästä syystä myöskään opetettava agentti ei tätä tietoa saa.

Vahvistusoppimisen agentti toimii Apros- simulointi ympäristöstä saatavan datan pohjalta. Simulaatio validoidaan Metropolian ammattikorkeakoulun ilmanvaihtolaboratoriossa. Simulaation pohjalta agentin päätöksenteolle lasketaan palkkio, seuraavan palkkiofunktion mukaisesti (1)

$$P = C_1 \times \Delta E - C_2 \times \Delta I \quad (1)$$

Palkkiofunktiossa ΔE kuvastaa energiansäästötarpeen ja hetkellisen energiankulutuksen erotusta, jota painotetaan painokertoimella C_1 . ΔI kuvastaa ilmanlaadun poikkeamaa ja on painotettu summa lämpötilan, ilmankosteuden ja CO_2 poikkeamista. Painokertoimien C_1 ja C_2 avulla kuvataan sitä, miten energiansäästö ja siitä syntyvä ilmanlaadun heikkeneminen on liiketoimintapäätös ja siten säädeltävissä oleva parametri.

4 Lähteet

- [1] Aarnio, Markus. Cruise Ship Handbook. Cham, Switzerland: Springer, 2022. Print.
- [2] A. Marashian et al., "Optimizing Cruise Ship Speed Incorporating Weather and Hotel Load Factors," 2024 European Control Conference (ECC), Stockholm, Sweden, 2024, pp. 1642-1647, doi: 10.23919/ECC64448.2024.10591006.
- [3] Shipping and the Environment: Improving Environmental Performance in Marine Transportation, edited by Karin Andersson, et al., Springer Berlin / Heidelberg, 2016. ProQuest Ebook Central
- [4] Karhula, N.; Sierla, S.; Ihasalo, H.; Ketomäki, J.; Huotari, M.; Vyatkin, V. Primary Frequency Control with an Air Handling Unit. Energies **2024**, *17*, 3777. <https://doi.org/10.3390/en17153777>

Mikael Filppula*, Harry Edelman, and David Hästbacka

Heating Control of Residential Building Apartments with IoT and Presence Estimation

Abstract: Heating is a major sink for energy consumption in the Nordic countries. To improve energy efficiency, home automation and smart radiator thermostats have been used to reduce unnecessary heating. However, the barrier to entry for this kind of automation can be high for older buildings where drastic new installations are not possible and the inhabitants may lack the technical know-how or motivation to operate home automation. Furthermore, even modern smart radiators may only use a rigid schedule to automate when to turn off the heat. In this paper, we examine how a heating automation system could be retrofitted into an apartment complex while requiring minimal new installations and low maintenance to upkeep. In addition, we attempt to further optimize energy use by using presence detection to further lower energy use when the apartments are empty. As a result, a wireless and batteryless home automation system was developed and tested for a month in three phases: control period, fixed schedule period, and finally a period with presence detection on top of the fixed schedule. Major energy savings minimum of 20 percent were gained using a fixed schedule compared to consumption during the control period. However, presence detection did not seem to improve the savings significantly compared to the fixed schedule.

***Corresponding Author: Mikael Filppula:** Tampere University, E-mail: mikael.filppula@tuni.fi

Harry Edelman: Turku University of Applied Sciences, E-mail: harry.edelman@turkuamk.fi

David Hästbacka: Tampere University, E-mail: david.hastbacka@tuni.fi

1 Introduction

Heating is a major sink for energy consumption in the Nordic countries. According to [1], in 2020 heating energy comprising roughly 64 percent of total yearly energy consumption in households in Finland. To improve energy efficiency, home automation through smart radiator thermostats has been used to lower heating when no one is at home or during the night when lower room temperatures are acceptable, even favorable for health reasons [2]. However, the barrier to entry for this kind of

automation can be high for older buildings where drastic new installations are not possible and the inhabitants may lack the know-how or motivation to operate home automation. Furthermore, even modern smart radiators may use only a rigid schedule to automate when to turn off the heat, meaning any spontaneous absence from home still wastes heating energy.

In this paper, we examine how a heating automation system could be retrofitted into an apartment complex while requiring minimal new installations and low maintenance to upkeep. In addition, we attempt to further optimize energy use by using a camera facing the entrance and a machine learning algorithm to detect whether anyone is home or not and adjust the heating accordingly.

2 Proposed solution and system setup

A wireless and batteryless home automation system was developed and is illustrated in Figure 1. Raspberry Pi 3 was used as the main hub. Due to the strict requirements set on the thermostats, Micropelt's MVA 005 thermostats was seen as the only viable candidate to act as a controller for the radiators providing the heat. The thermostat harvests heat energy from the radiator to power itself to remain batteryless and wireless, and could be controlled using EnOcean messages. Since Raspberry Pi 3 doesn't have inherent ability to communicate via EnOcean messages, USB300 component was installed into the hub to enable communication to the thermostats. Finally, to enable presence detection, a small camera was installed and connected to the hub. The camera would monitor the main entrance and send graphical data to the presence detection algorithm, which would finally give its evaluation whether anyone was in the apartment or not.

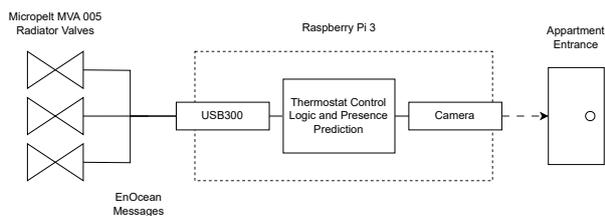


Fig. 1. Overview of the control system

3 Experiments and results

The developed system was tested for a month in three phases: control period, fixed schedule period, and finally use of presence detection on top of the fixed schedule. During the control period thermostats were set to 22°C to gauge the maximum energy consumption. In fixed schedule thermostats were set to 22°C during the day, but were instructed to lower the temperature to 18°C during the night, from 22:00 to 6:00. Finally during the last test period, thermostats received further instructions to lower or increase the temperature based on the presence prediction algorithm; temperature was kept at 22°C during the day, but adjusted to 18°C if the apartment was assumed empty.

The heating energy consumption measurements were compared to a baseline building of similar size, structure, and occupancy. During the baseline control period, the difference in median power input between the buildings was only 1.14% and 0.28% in terms of average power input, both being lower in the experimental building.

During the fixed schedule period, the baseline building had 21.29% higher median power input and 9.45% higher average power input than the experiment building. These results agree with the results made in other studies researching scheduled thermostats, such as [3] and [4]. However, the performance with presence detection did not drastically differ from the results gained from the fixed schedule. There may be multiple reasons for this, such as inaccuracies with the algorithm, inhabitants working remotely and not leaving their apartments, or the testing being done during early spring instead of the middle of winter. Furthermore, the test periods may have been too short to average out the variances caused by the human activity in the apartments.

Some thermostats lost connection to the database during the tests. Due to their low transmission strength, some may have been too obstructed by furniture, appliances or walls to reach the hub device. In addition, some thermostats were unable to harvest enough power from

the radiators for one reason or the other, which caused them to drain out and shut down. While the majority of the thermostats functioned correctly during the experiment, the reduced control over some of the radiators diminished the energy savings compared to the ideal performance.

Acknowledgement

This project has received funding from Business Finland in the AIDOMUS project.

References

- [1] Tilastokeskus. Asumisen energiankulutus. 2020;. URL https://stat.fi/til/asen/2020/asen_2020_2021-12-16_tie_001_fi.html
- [2] Tham S, Thompson R, Landeg O, Murray K, Waite T. Indoor temperature and health: a global systematic review. *Public Health*. 2020;179:9–17.
- [3] Ayan O, Turkay B. Smart Thermostats for Home Automation Systems and Energy Savings from Smart Thermostats. In: *2018 6th International Conference on Control Engineering Information Technology (CEIT)*. 2018; pp. 1–6.
- [4] Sönmez D, Dinçer K. A review of modern residential thermostats for home automation to provide energy efficiency. In: *2016 4th International Istanbul Smart Grid Congress and Fair (ICSG)*. 2016; pp. 1–4.

Long Phan*, Saku Pöysäri, and Jyrki Latokartano

Achieving Industry 4.0 in manufacturing SMEs: A Case Study on Digital Twin Integration for Industrial Robots and Legacy Systems

Abstract: Industry 4.0 has driven the digitalization of manufacturing industries, with digital twin (DT) technologies emerging as a competitive edge. However, while large companies with extensive resources are leading this front, small and medium-sized enterprises (SMEs) – particularly in discrete manufacturing (DM) - are lagging behind in this digital trend. Some main reasons for this are high technical complexity, financial constraints, scalability issues, legacy system integration, and the volatile nature of DM SMEs. To address some of these challenges, this paper presents an approach for adopting DT tailored to manufacturing SMEs, realizing by a partial proof-of-concept. This DT system integrates industrial robot and manufacturing equipment: both modern and legacy devices. It features the use of OPC UA to integrate technologically constrained hardware. This approach highlights a DT system with security, reliability, scalability, and real-time control, while keeping the cost reasonable and compatible with legacy hardware.

Keywords: digital twin, discrete manufacturing, SMEs

***Corresponding Author:** Long Phan, Tampere University, Finland, E-mail: long.phan@tuni.fi

Second Author: Saku Pöysäri, Tampere University, Finland, E-mail: saku.poyasari@tuni.fi

Third Author: Jyrki Latokartano, Tampere University, Finland, E-mail: Jyrki.latokartano@tuni.fi

1 Introduction

Since the introduction of the Industrial 4.0 in the early 2010s, the manufacturing industry has seen transformative advancements in digital technologies. Manufacturing companies are in the race toward the concept of the “smart factory”, where optimization and efficiency promise the greatest rewards [1]. To gain a competitive edge, many companies have started to adopt DT – a technology with many potential and perceived benefits that can revolutionize manufacturing processes [2]. However, while large

companies with substantial resources are leading this transformation, SMEs – particularly in DM – are lagging behind. Their key challenges in deploying DT are high technical barriers, financial constraints, scalability issues, legacy system integration, and the inherent volatility of DM SMEs [3].

Despite these pressing obstacles, there are limited research in (1) quantifying the impact of DT in DM SMEs and (2) developing flexible, scalable, and cost-effective DT adoption strategies, including approaches for legacy system integration. The immaturity of new technologies and the integrability of existing ones cause technological risks, which in turn reduce companies' willingness to utilize DTs [4].

To address these topics, this paper aims to present an approach for adopting DT tailored to DM SMEs, demonstrated through a partial proof-of-concept implementation. This DT setup at cell level integrates robotics and manufacturing equipment, from modern wireless tools to legacy devices that have limited communication capabilities. To integrate the wide range of hardware, this DT system features the use of OPC UA. This approach highlights a DT system with security, reliability, scalability, and real-time control, while keeping the cost reasonable and compatible with legacy hardware. Through this practical DT solution, this research seeks to provide DM SMEs with a practical digital twinning approach, enabling them to remain competitive in an increasingly digitalized market.

2 Background

This study is a part of a Master's Thesis conducted at Tampere University, Faculty of Engineering and Natural Sciences. In this study, the definition of a Digital Twin is derived from [5], which requires a bidirectional flow of data between an existing physical object and its digital counterpart to achieve full integration.

3 Aims

The overall aim of this research is to propose a realistic

approach for developing DT tailored to DM SMEs, enable them to have more options when adopting this emerging technology. This method emphasizes the use of OPC UA and legacy system integration while keeping the cost reasonable and ensuring scalability. While this research primarily focuses on proposing an approach, it

is a part of a larger project to develop a fully functional DT system. Preliminary results from this partial case study are also presented in this paper, offering insight into the practical feasibility and initial implementation challenges of the proposed approach.

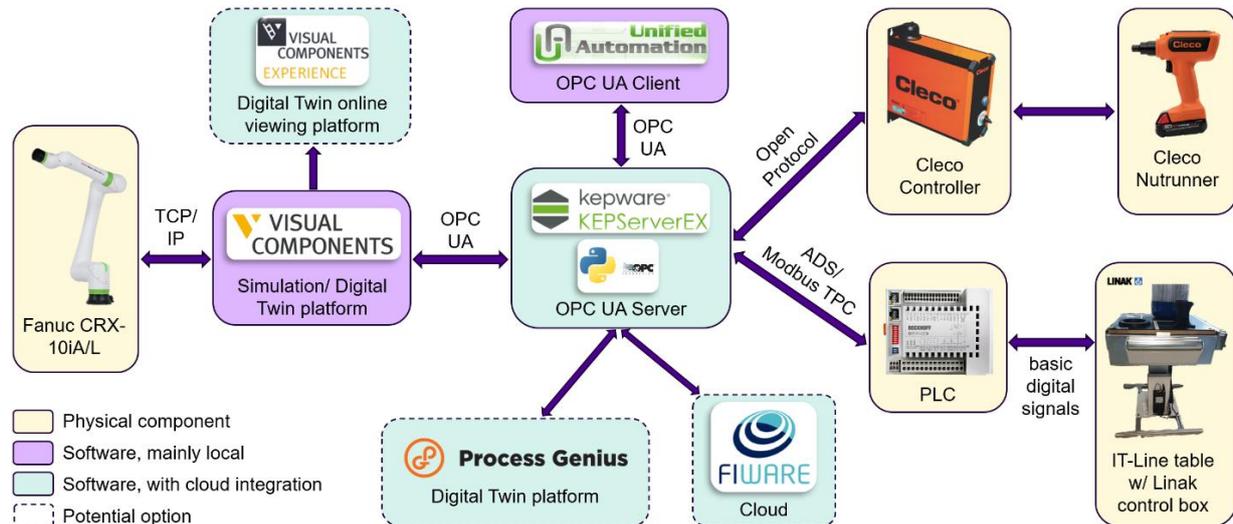


Figure 1: Digital Twin system integration diagram

4 Materials and Methods

Figure 1 illustrates the Digital Twin setup used in this study, highlighting physical equipment (yellow boxes), software components (purple and green boxes), and their connections via communication protocols indicated by labeled purple arrows.

The physical components: The main physical hardware of the system includes a Fanuc robot CRX-10iA/L, Cleco cordless nutrunner CCBPW223 and its controller mPro200GC, and an IT-Line height-adjustment table with Linak control box CBD6SP00020A-009.

The virtual “twin”: The digital 3D representation of the system is modelled in and with Visual Components.

The connection and integration: At the heart of this DT system is the OPC UA server – where all physical and virtual components are connected to. This server facilitates information exchange between controllers, PLC, 3D models, OPC UA client, and other platforms.

Legacy device integration: The height-adjustment assembly table with Linak’s controller - classified as a legacy device in this study – does not have advanced communication protocols. By default, the controller uses LinBus to connect with a computer for basic parameter configuration but lacks real-time monitoring and bidirectional communication. This study aims to establish two-way communication with an OPC UA server by (1) integrating a PLC to send commands to the Linak’s controller and (2) installing sensors for feedback. These modifications enable real-time control

and monitoring, ensuring continuous information flow.

5 Bibliography

- [1] L. S. Dalenogare, G. B. Benitez, N. F. Ayala, and A. G. Frank, “The expected contribution of Industry 4.0 technologies for industrial performance,” *Int. J. Prod. Econ.*, vol. 204, pp. 383–394, Oct. 2018, doi: 10.1016/j.ijpe.2018.08.019.
- [2] I. Onaji, D. Tiwari, P. Soulatiantork, B. Song, and A. Tiwari, “Digital twin in manufacturing: conceptual framework and case studies,” *Int. J. Comput. Integr. Manuf.*, vol. 35, no. 8, pp. 831–858, Aug. 2022, doi: 10.1080/0951192X.2022.2027014.
- [3] M. Slot, R. Damgrave, and E. Lutters, “A structured digital twinning approach to improve decision-making in manufacturing SMEs,” *CIRP J. Manuf. Sci. Technol.*, vol. 55, pp. 359–374, Dec. 2024, doi: 10.1016/j.cirpj.2024.10.010.
- [4] M. Gulewicz, “Digital twin technology — awareness, implementation problems and benefits,” *Eng. Manag. Prod. Serv.*, vol. 14, pp. 63–77, Mar. 2022, doi: 10.2478/emj-2022-0006.
- [5] W. Kritzinger, M. Karner, G. Traar, J. Henjes, and W. Sihn, “Digital Twin in manufacturing: A categorical literature review and classification,” *IFAC-Pap.*, vol. 51, no. 11, pp. 1016–1022, Jan. 2018, doi: 10.1016/j.ifacol.2018.08.474.

Markku Ohenoja*, Aki Sorsa and Mika Ruusunen

Interpretable machine learning for transparent industrial applications

Abstract: Decision-making needs typically be transparent and this applies also to model-based design and operation in process industries. User trust is also important to ensure that the developed mathematical models are accepted by practitioners. However, modern artificial intelligence approaches can result in overcomplex models with limited interpretability. This research discusses the topic of interpretable models and studies the applicability of one method in several case studies related to process automation and process engineering. The approach enhances model interpretability and ensures that models can be effectively integrated and maintained with minimal disruption.

Keywords: model complexity, multiple linear regression, genetic algorithms, hydrothermal liquefaction

*Corresponding Author: Markku Ohenoja: University of Oulu, Finland, E-mail: markku.ohenoja@oulu.fi

1 Background and aims

Mathematical models in process automation and process engineering must be explainable for several reasons. First of all, understandable models can result in significantly higher user trust. Secondly, more transparent models provide clear insights into predictions and ensure that the decision-making process is understood and accepted. When models are explainable, it is easier to identify and address errors or biases, thus ensuring that the model's decisions are fair and unbiased.

The model structures generated with artificial intelligence (AI) tools, such as machine learning (ML) or deep learning can be very complex. Explainability is key for responsible AI development, ensuring transparency, accountability, and trustworthiness. Interpretable insights provided by explainable models offer valuable information about data relationships and patterns, which can be particularly useful for domain experts. Additionally, explainable models facilitate collaboration between data scientists and domain experts, leading to more effective and impactful

solutions.

According to (Hu et al., 2021), although model complexity is a fundamental problem in deep learning, it still has been in the infant stage. Relevant tools and practices for traceability of AI models to elaborate reproducible or repeatable data analysis have been reviewed by (Mora-Cantalops et al., 2021). Among the practical approaches for interpretable models, LIME (local interpretable model-agnostic explanations) algorithm has been used for different applications, such as wind power forecasting (Yang et al., 2023). Generic methods for more interpretable ML involve using linear, surrogate or rule-based models, and sensitivity analysis, among others.

This work highlights the applicability of a studied ML method being able to produce such interpretable models for process engineering applications. The methodology has been applied in several case studies and this presentation collects the results and also uses the method in a novel problem related to production of green aviation biofuels.

2 Material and methods

The ML method used here is based on Genetic Algorithms (GA) and results in a multiple linear regression model (MLR) with respect to features, but non-linear with respect to real measurements. The algorithm selects variables and performs functional transformations from a pre-defined list, creating features. It then selects mathematical operations (add, multiply, divide) between the features. Thus, GA creates many candidate model structures, evaluates their performance, and uses GA operations (reproduction, mutation, elitism) to generate new populations until convergence or calculation budget is reached. This approach helps build an easily interpretable model and adds user trust. The implementation of the algorithm is described in detail in (Ohenoja et al., 2018) and (Sorsa et al., 2013).

In this work, the method is applied to a dataset consisting of quality control system measurements of a paperboard production line, and to a dataset comprising the reaction conditions and biocrude yield

in hydrothermal liquefaction of microalgae. The latter dataset can be found in (Mordechai Koskas et al., 2023) and was in this study screened to *Chlorella Vulgaris* algae species.

3 Results

In (Ohenoja et al., 2018), the proposed ML approach was successfully applied to model the polarization curve of fuel cells in different operation conditions. In (Sorsa et al., 2013), it was applied to Barkhausen noise data set to predict stress in steel samples. Both studies demonstrated the method's capability for small datasets and effectiveness in capturing complex relationships within the data.

Regarding the case of predicting the reel dry weight in a two-ply board machine, the dataset contained 64 selected measurements and over 500,000 data points. The mean absolute percentage error (MAPE) of 2.89% was achieved with the proposed ML approach. The identified model utilized five explanatory variables, which were related to the wire speed, headbox ash content, and water and pulp consistencies. The selected variables are also intuitively closely linked to the produced paper grade, and thus the reel dry weight, supporting the successful variable selection of interpretable model. The final selected variable (or its feature) was the pressure filter reject flow rate, having a less intuitive effect to the predicted variable.

Table 1. Model performance metrics in HTL case. Error metrics are calculated from normalized values using test data set ($n=17$).

Model	RMSE [-]	R [-]	MAPE [%]
Kinetic	0.2969	-0.24	81.9
MLR	0.2072	0.63	64.1
PLSR	0.2069	0.63	64.0
PCR	0.2066	0.61	26.7
ANN	0.1930	0.71	65.3
GA	0.1891	0.73	46.0

The second case study aimed to predict the biocrude yield (Y_{BC}) in hydrothermal liquefaction (HTL) process, an intermediate step in production of green aviation biofuels. Several modeling approaches were tested, such as the kinetic model in (Sheehan & Savage, 2017), and typical ML approaches including MLR, PLSR, PCR and ANN. The model performance metrics are given in Table 1. The GA-based approach outperformed other methods tested in terms of correlation coefficient (R) and root mean squared error (RMSE) and had the second lowest MAPE value. The final model structure with four explanatory variables (residence time RT , feed biomass protein content, F_P , temperature T , feed biomass carbohydrate content F_C) was:

$$Y_{BC} = a_0 + a_1RT^{-1} + a_2\frac{\sqrt{F_P}}{T} + a_3T^3 + a_4F_C^3.$$

4 Conclusions

The proposed GA-based ML method identified usable features and interpretable models in earlier published case studies and in two new cases presented in this paper. Such models can gain user trust due to their simple model structure. In addition, regression models are easy to implement in industrial automation systems and require less complex maintenance. This approach not only enhances model interpretability but also ensures that models can be effectively integrated into existing systems with minimal disruption.

Future work could explore the application of this method to other domains and further refine the algorithm to improve its efficiency and accuracy. Additionally, incorporating user feedback into the model development process could lead to even more robust and trustworthy models.

5 References

- Hu et al. (2021). Model complexity of deep learning: A survey. *Knowledge and Information Systems*, 63(10), 2585–2619.
- Mora-Cantalops et al. (2021). Traceability for Trustworthy AI: A Review of Models and Tools. *Big Data and Cognitive Computing*, 5(2).
- Mordechai Koskas et al. (2023). Process simulation for mass balance of continuous biomass hydrothermal liquefaction with reaction kinetics. *Energy Conversion and Management: X*, 20, 100477.
- Ohenoja et al. (2018). Model Structure Optimization for Fuel Cell Polarization Curves. *Computers*, 7(4).
- Sheehan & Savage (2017). Modeling the effects of microalga biochemical content on the kinetics and biocrude yields from hydrothermal liquefaction. *Bioresource Technology*, 239, 144–150.
- Sorsa et al. (2013). An Attempt to Find an Empirical Model between Barkhausen Noise and Stress. *Materials Science Forum*, 768–769, 209–216.
- Yang et al. (2023). Investigating black-box model for wind power forecasting using local interpretable model-agnostic explanations algorithm: Why should a model be trusted? *CSEE Journal of Power and Energy Systems*, 1–14.

Mikko Haikonen*, Hannu Toivonen, and Jerker Björkqvist*

Stress test evaluation of classifiers for audio based bearing diagnostics in HVAC machines

Keywords: Diagnostics, Machine learning, Bearing monitoring, Audio classification, HVAC maintenance

***Corresponding Author: Mikko Haikonen:** Solita Oy, E-mail: mikko.haikonen@solita.fi

Hannu Toivonen: Åbo Akademi University, E-mail: hannu.toivonen@abo.fi

***Corresponding Author: Jerker Björkqvist:** Åbo Akademi University, E-mail: jerker.bjorkqvist@abo.fi

Ability to correctly classify the audio signals from before and after overhaul was primary objective. Attention was also paid to the computational cost of the classifiers. An additional aim was to provide additional sanity check mechanisms to avoid selecting a classifier that is being overfit. For this we examined how lossy compression of input data affects the classification performance. This is how we estimated the reliability of K-fold cross validation results.

1 Background

Condition based monitoring attempts to measure the situation of industrial equipment or process. This measurement is important in detecting equipment changes or damages. Servicing mechanical devices has traditionally been relying heavily on aural observations. Accurate audio diagnostics require profound understanding. Those skills are not always available on site, especially for remote location. Therefore automated or assisted diagnostics are very interesting fields in predictive maintenance.

2 Objectives

In applying machine learning classifiers in condition based monitoring there are two practical problems. The first one is the overfit of classifiers. That may cause problems whenever the situation changes at monitored process after training data is being collected and the classifier is being trained. The second problem is the cost of audio data storage. Data compression is one of the ways to decrease data storage costs. However, it is not always clear how much information we can afford to lose in order to maintain appropriate classification performance.

The objective of our study was to evaluate classifiers in their capacity to detect the relationship between the selected audio features and bearing changes. Audio samples from HVAC (heating, ventilation, and air conditioning) system were used for classification experiments. Main focus in evaluation was to prevent overfit.

3 Methods

We used the audio samples collected from an HVAC system before and after overhaul. In the overhaul one of the two drive and fan unit was replaced with new one. Audio signals from air- and contact microphone were recorded. To avoid excess computations the amount of data was reduced by random sampling of training and testing audio files.

The audio classification features were selected in a way that attempts to reduce the need for additional feature engineering if the detection task changes. We used a feature space that allows linking the classification results back to the physical process. Therefore we used features like spectrum (FFT), autocorrelation (ACF) and partial autocorrelation (PACF). An additional benefit of ACF and PACF features is their close link to data generating process characteristics [1]. Autocorrelation feature can also bring insights into summative- and modulation effects [2]. Both autocorrelation and partial autocorrelation are also closely linked to linear predictive coding used in human speech processing [3].

For classification we used random forest, support vector machines (SVM), learning vector quantisation and decision tree. We used relatively simple models to maintain the link between results and a physical process. That link is useful when the classification results are taken into operational use.

The process of training and cross-validating classifiers was used as tool to understand how well the selected feature space reflects the mechanics and the class of samples. Our stress test complemented the results from traditional cross validation results.

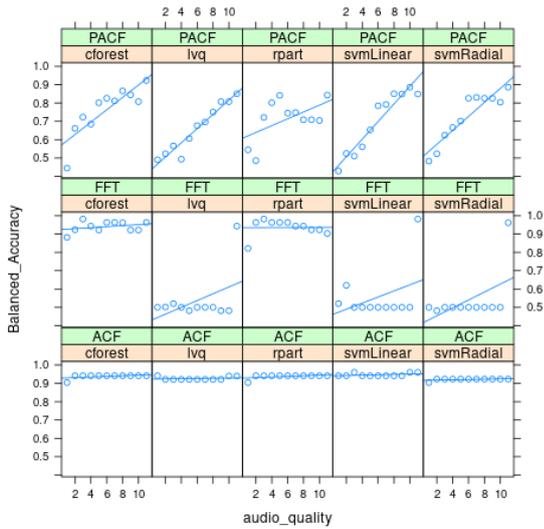


Fig. 1. Example stress profiles: Impact of audio quality to balanced accuracy in Stress test results for selected classifiers and feature sets (horizontal axis of individual plots is audio quality indicator where 0 stands for poorest and 11 is original audio recording)

Traditional cross validation methods including e.g. K-fold [4] cross validation were used [5]. Our key idea was to extend e.g. K-fold cross validation by stress testing the classifiers. Stress test means that the trained classifiers are stressed by testing them with samples of varying audio quality. For each classifier and validation sample, we used several levels of audio quality. We will then examine how the prediction accuracy reacts to this stress. The purpose of the stress test was to examine how sensitive the classifiers are to changes in input data. From this experiment, we obtain a stress profile for each classifier and each type of audio feature. We used these stress profiles to find the best combination of classifier and feature set for the task at hand.

Since analysis of audio samples and speech analysis are similar problems it is very natural to use speech compression as a vehicle for stress testing the classifiers and consider audio samples as "machine speech".

4 Results

Stress test results fig. 1 indicate that a good classification performance in K-fold cross validation tests fig. 2 may drop dramatically with slightest reduction of input data quality. Example of such a classifier was support vector machine (SVM) trained and tested using FFT

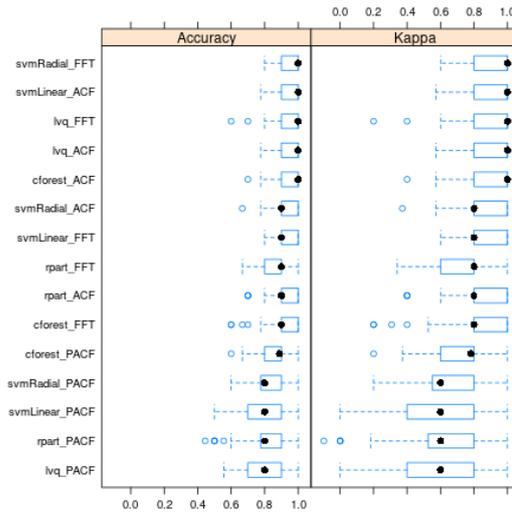


Fig. 2. Cross validation results: One can compare these cross validation to find classifiers that perform well in cross validation and very poorly in stress test

feature set. We also experienced that the classifier performance depends on selection of the feature set even if two feature sets have direct mathematical translations like spectrum and autocorrelation (ACF) features do. These sensitivities are not always seen in cross validation results but regrettably also depends on selection of K-fold parameters.

References

- [1] Box G E, Jenkins G M. *Time Series Analysis, forecasting and control*. Holden-Day Inc. 1976.
- [2] Lange H F. *Correlation Techniques*. Iliffe Books Ltd. 1967.
- [3] Rabiner Lawrence R, Schafer Ronald W. *Introduction to Digital Speech Processing*. now Publishers Inc. 2007.
- [4] T Hastie, R Tibshirani, J Friedman. *The Elements of Statistical learning*. Springer Science Business Media. 2009.
- [5] Kuhn M, Johnson K. *Applied Predictive Modeling*. Springer Science+Business Media. 2013.

Jaakko Etto ja Heikki Isometsä

Kehittyvä ja muuttuva teollisuuden prosessiautomaation laboratorio

Asiasanat: automaatiojärjestelmä, automaatio, elinkaari, oppiminen

Heikki Isometsä: Lapin ammattikorkeakoulu, E-mail: heikki.isometsa@lapinamk.fi

Jaakko Etto: Lapin ammattikorkeakoulu, E-mail: jaakko.etto@lapinamk.fi

1 Johdanto

Vuoden 2020 kevään koronan tuomat haasteet toivat käytännön opetukseen muutoksia koko Suomessa, niin myös Lapin ammattikorkeakoulun Kemian kampuksella. Vuonna 2019 opetusprosesseissa tehdyn automaatiokoulutuksen ulkopuolisen auditoinnin tuloksena oli ryhdytty jo suunnittelemaan isoja uudistuksia varsinkin prosessiautomaation opetusympäristöihin. Osaltaan näiden edellä mainittujen asioiden vaikutuksesta on uusiin opetusympäristöihin toteutettu monipuolisia oppimismahdollisuuksia, joita voidaan hyödyntää niin automaation, sähkövoimatekniikan kuin kunnossapidon oppimisessa. Vuosina 2020–2024 on uudistuksia tehty kaikkiin automaatio-opetuksen luokkiin ja laboratorioihin. Uudistukset ja kehitystyö jatkuvat yhä ja tarkoitus onkin, että uudet ympäristöt mahdollistavat jatkuvan kehityksen pieninä kokonaisuuksina. Opetusympäristöjen ja laboratorioiden matalista käyttöasteista puhutaan usein. Uusista laboratorioympäristöistä on tästä syystä tehty ns. hybridilaboratorioita, joita voidaan käyttää etänä ja ohjatusti tai ohjaamatta paikan päällä. Laboratorioiden turvallisuuteen on myös kiinnitetty huomiota ja mahdollistettu opiskelijoille laboratorioiden käyttö heidän aikatauluunsa sopivasti. Opiskelijoita on myös kuultu ja heidän kokemuksiaan ja mielipiteitä on pyritty hyödyntämään kehitystyössä.

2 Monisoluinen muuttuva laboratorio

Uudessa laboratorion toimintamallissa on pyritty useamman opiskelijaryhmän samanaikaiseen opiskeluun ja käytännön tekemiseen riippumatta toisten ryhmien projektien tilanteista. Laboratorion teollisuusprosessina toimii monisoluinen eli 12-soluinen prosessi. Prosessin solut ovat toiminnaltaan samankaltaisia, mutta ne on toteutettu toisistaan poikkeavilla eri valmistajien pumppauskäyttöillä ja kenttäinstrumentoinnilla.

Prosessiautomaatiolaboratoriossa opetetaan tehdas- ja tuotantoprosesseja turvallisesti käyttäen väliaineena vettä. Energiatehokkuuden näkökulmasta voidaan mitata sähköenergian ja paineilman käyttöä.

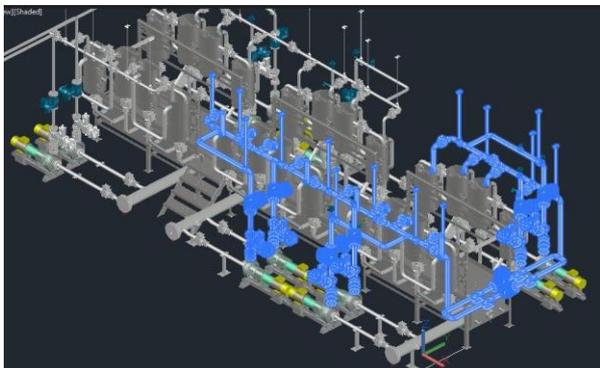
Vähähiilisyttä laboratorio tukee etäkäyttömahdollisuuden kautta, jolloin varsinkin monimuoto-opiskelijan ei tarvitse aina tulla paikanpäälle laboratorioon. Laboratorion laitteistot, automaatiojärjestelmät ja nykyaikaiset tiedonsiirtoväylät toimivat sekä opetuksessa että käytännössä.



Kuva 1. Teollisuusprosessin valvomotila (Kuva: Pia Kuha, Lapin AMK)

Monisoluisuudella mahdollistetaan laitteiston päivitysmahdollisuudet pienissä osissa solu kerrallaan ja elinkaarimallin toteutus myös käytännössä.

Pieniä osaprosesseja, soluja, voidaan ohjata omina osinaan, tai rakennetun kahden runkolinjan kautta



Kuva 2. Runkolinjat 1 ja 2 (Runkolinja 2 sinisellä)

voidaan yhdistää kuusi osaprosessia laajemmaksi prosessiksi. Tämä mahdollistaa esimerkiksi kahdennuksen opettamisen käytännön tasolla.

Prosessin kenttäinstrumentaatiossa on peruskenttäinstrumentaation lisäksi paljon myös älykkäitä kenttäinstrumentteja. Perussignaaleista käytössä on mA-viestit ja HART-tekniologia (Highway Addressable Remote Transducer). Näiden teollisuuden yleisimpien signaalien lisäksi käytetään Bluetooth-tekniikkaa, Profinet-kenttäväylää, WLAN-tekniikkaa ja rakenteilla on myös APL-tekniikkaa käyttävä prosessisolu.



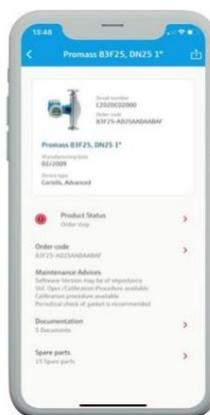
Kuva 3. Osaprosessi ja ohjauskeskus (Kuva: Pia Kuha, Lapin AMK)

Opiskelijat pääsevät tutustumaan laboratorioon 3D-mallin (Kuva 2) avulla ja Matterport-ympäristön kautta ennen työskentelyä laboratorion oppimisympäristössä.

3 Automaatio- ja sähkövoimatekniikka

Uutta laboratoriota voidaan hyödyntää jokaisella automaatioinsinööriopiskelijan vuosikursilla. Osa opiskelijoista ei ole opintojen alussa koskaan käynyt teollisessa prosessiympäristössä ja nähnyt oikeita prosessin laitteita, valvomoa (Kuva 3), keskuksia, kaapelointeja, pumppuja, putkistoja ja säiliöitä.

Automaation perusteiden opiskelussa voidaan tutustua laitteisiin paikan päällä hakien tietoa tyyppikilpien ja QR-koodien kautta sekä sovelluksilla (Kuva 4). Prosessin rakenteiden osien ja laitteiden tunnistamista voidaan harjoitella esim. laitelistauksilla ja PI-kaavioilla.



Kuva 4. Endress+Hauser Operations App (Endress & Hauser 2025)

Ohjaustekniikkaa voidaan myös opiskella prosessin 12 pumpun, moottorin piirikaavioiden ja taajuusmuuttajien parametrintien kautta. Sähkövoimatekniikan opinnoissa laboratoriota voidaan hyödyntää erilaisissa moottorikytkentöjen ja mittauksen yhteydessä. Todellisia lukitusehtoja, säätöratkaisuita ja käynnistystapoja voidaan opiskella ympäristössä kohteessa, jossa moottorilla on prosessin toiminnan vaatima kuormitus. Sähkövoimatekniikan opinnoissa voidaan harjoitella myös käyttöönottomittauksen tekemistä teollisuuden prosessiympäristöissä.

4 Automaation syventävät opinnot

Automaatio-opiskelun syventävissä opinnoissa opiskelijat perehtyvät suunnitteluun, tarkastuksiin, kalibrointiin sekä mittaus- ja ohjaussignaaleihin.

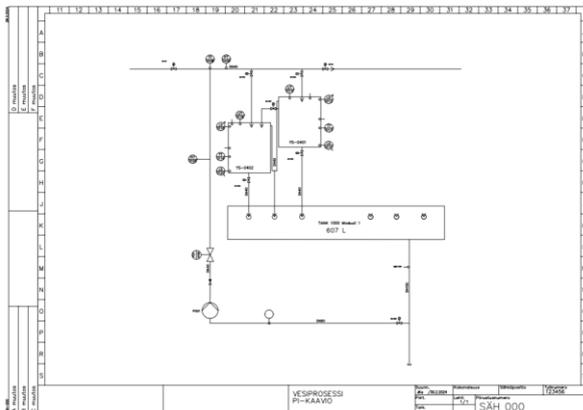
Prosessiautomaatiossa on laajasti laitteistoa ja paljon opittavaa. Oppimisympäristö tarjoaa opiskelijoille paljon tutkimista. Turvallisuusasiat ovat kuitenkin

tämän päivän teollisuudessa asia nro 1. Insinööriopiskelijoille opetetaan tämän prosessin avulla myös turvallisuusasioita ja esimiehen vastuuta sekä automaatioinsinöörin vastuuta.

Prosessin monipuolisuus antaa mahdollisuuden tehdä töitä ja harjoituksia yksin ja ryhmissä. Laajat opintokokonaisuudet tehdään projekteissa, joissa opiskelijat ovat 3–4 hengen projektiryhminä.

Yksi ensimmäisistä tehtävistä syventävissä opinnoissa on SFS-12100 mukainen riskinarviointi ja riskin pienentäminen teollisuusprosessin automaation oppimisympäristössä.

Laboratorion opetussoluja voidaan hyödyntää suunnittelusta lähtien asennusten ja koestuksen ja tarkastusten kautta käyttöönottoon ja prosessin ohjaamiseen ja säätämiseen asti. Opettajaa ei aina tarvita kertomaan opiskelijalle tai projektiryhmälle, ovatko he onnistuneet työssään. Osaprosessin käynnistys ohjauspaneelilta tai valvomosta kertoo sen opettajan puolesta.



Kuva 5. Suunnitteluvaihe



Kuva 6. Osaprosessin käyttöliittymä

Suunnitteluvaiheessa voidaan suunnittelua tehdä PI-kaavioiden, virtauskaavioiden, piirikaavioiden ja

säätökaavioiden kautta. Projektiryhmillä on mahdollisuus työskennellä laboratoriossa myös ”pakollisten” laboratoriotuntien lisäksi muuna haluamansa ajankohtana.

Teoriaopintojen signaalit ja IO-liittynät tulevat tutuiksi käytännön prosessiautomaatioprojektissa. Piirikaavioiden ja PI-kaavioiden merkinnät (Kuva 5) siirtyvät ohjelmistoihin, parametreihin ja laitteisiin todellisina merkintöinä ja toimintoina (Kuva 6). Dokumentoinnin merkitys tulee opiskelijalle tutuksi harjoitusprojektien myötä.

Projektin edetessä käyttöönottoon on mahdollista tehdä SIMIT-prosessin simulointiohjelmalla varsin tarkka simulointimalli ja testata ohjelmaa simulaattorin kanssa. Kenttäinstrumentaation oikeat asennukset (PSK-käsikirja 2) tarkastetaan laiteohjekirjojen ja SFS5059 standardin mukaisesti. Signaalien kulku kenttäinstrumentaation ja automaatiojärjestelmän välillä pystytään tekemään simuloimalla signaalia HMI-tai valvomonäytölle. Oppimisympäristön prosessien automaatiojärjestelminä käytetään Siemens- ja Valmet-ohjelmistoja ja prosessiasemia.

Oikein toteutetut mittaukset ja mittausten kalibrointi mahdollistavat laadukkaan tuotannon ja ohjauksen. Kalibroinnissa käytetään teollisuuden käyttämiä laadukkaita työkaluja. Esimerkiksi lämpötilaa ja painetta voidaan kalibroida Beamex MC6-T150-kenttäkalibraattorilla ja säätöventtiilejä Endress+Hauser Field Xpert SMT70-kentänhallintalaitteella HART-kommunikaatiota käyttäen (Kuva 7).



Kuva 7. Kalibrointivälineistöä

Laboratoriossa on myös mahdollisuus seurata ja verrata eri prosessin osien energian käyttöä ja tehdä sähkön laatumittauksia. Sähkön mittaukset on toteutettu Sentron PAC3220 -monitoimimittarilla. Kyseisillä laitteilla voidaan mitata mm. virta, jännite, teho, loisteho ja taajuusmittaukset (Kuva 8). Monitoimimittarit on myös liitetty automaatioverkkoon Profinet-väylän kautta valvomon ohjelmistoon. Apuenergiaista paineilmaa on mahdollista ohjata magneettiventtiileillä ja mitata

SMC:n AMS-laitteilla.



Kuva 8. Sähkön mittauksia Sentron PAC3220-laitteilla

Tavoitteena on opettaa opiskelijoille teoriaopetuksen, laboratorioiden harjoitusten ja projektien avulla laadukkaan mittaamisen ja säätämisen vaatimuksia ja erityyppisten asennus-, parametroidi- ja ohjelmointivirheiden mahdollisia vaikutuksia teollisuusympäristöissä.

Pidemmälle opinnoissaan edenneet opiskelijat pääsevät myös etäohjelmoimaan ja ajamaan prosesseja etänä. Osana etäkäyttöä opiskelijat oppivat myös kyberturvallisuuden ja etäkäytön vaatimuksia. Viimeisenä opiskeluvuotena automaation opiskelijat perehtyvät myös automaation tietojärjestelmiin.

Prosessiautomaatiolaboratoriosta saadaan kerättyä tietoa OPC-rajapinnankautta, ja sekin tulee käytännön harjoituksilla opiskelijoille tutuksi. Lisäksi tietoturvaan ja virtualisointiin paneudutaan opintojen loppuvaiheissa. Tärkeänä osana on myös tietokanta- ja raportointiharjoitukset. Opiskeluun sisältyy Teollisuus 4.0- ja 5.0- käsitteiden opiskelu, ja opiskelijat toteuttavat teollisen internetin simuloitun mallinnuksen käyttäen pilvipohjaista avointa IIoT-käyttöjärjestelmää (Platform as Service, Paas) ja IIoT-analyysin käyttäen tilastolliseen data-analyysiin kehitettyä ohjelmistoa.

5 Poikkitieteellinen käyttö

Teollisuuden prosessiautomaation laboratorion toteutus on onnistunut muiden opintojaksojen koulutustarpeiden, kuten kunnossapidon koulutuksen kannalta. Oppimisympäristö tarjoaa todellisia

teollisuusympäristöjä vastaavia tuotantoprosesseja, sähkökäyttöjä, pumppuja, kenttäinstrumentointia ja automaatiototeutuksia. Muiden kuin sähkö- ja automaatiotekniikan opintojaksojen opetuksessa on mahdollisuus parantaa laboratorion käyttöastetta.

Kunnossapidon koulutusmoduulien opintojaksojen, kuten tuotantolaitosten kone- ja laitekunnossapito, sähkö- ja automaatiokunnossapito, kunnossapidon työsuunnittelu käytännön harjoitustehtäviä tehdään tuotantoprosessien automaation oppimisympäristössä. Kunnossapidon opiskelijoista suurin osa on konetekniikan opiskelijoita, joille tuotantoprosessi antaa mahdollisuuden kunnossapidon käytännön tuotantoprosessien laitetuntemuksen, PI-kaavioiden ymmärtämisen, työsuunnittelun, huoltotöiden, työkohteiden turvallisen erottamisen ja mittavaan kunnonvalvonnan menetelmien oppimiselle.

Oppimisympäristössä laboratoriotöiden aiheina ovat esimerkiksi seuraavat tehtävät:

- osaprosessin PI-kaavion laitteiden tunnistus ja käyttötarkoitus (mm. PSK3601, PSK3605)
- putkistojen, säiliöiden ja virtaavien aineiden merkinnät (PSK0901, PSK 0902, PSK0903)
- prosessin erottamisen suunnittelu ja hallinta (PSK3604)
- sähkömoottorin ja pumpun linjaus (PSK8301) (Kuva 9)
- kunnonvalvonnan värähtelymittaus (PSK57)
- kunnonvalvonnan sähköiset menetelmät (PSK77)
- instrumenttiasennusten tyyppi- ja piirustukset (PSK52)
- kulkutiet ja työskentelytasot (PSK47)
- osaprosessin ohjaus, toiminta ja lukitukset (automaation lehtorin toteuttama)
- sähköistyksen käyttöönottotarkastukset (PSK2920)
- liikkeen vahvistuskameran käyttö prosesseissa
- lämpökameran käyttö ja kuvien analysointi.



Kuva 9. Linjaus prosessiautomaation laboratoriossa. (Promaint 2023)

6 Yhteenveto

Teollisuuden prosessiautomaation laboratorion toteutus on osoittautunut onnistuneeksi sekä opettajien kokemusten että opiskelijoiden palautteen perusteella.

Useita kehitysasioita on virinnyt uusiin opetuslaboratorioihin liittyen. APL-tekniikkaa sisältävä osaprosessi on myös rakenteilla, kuten aikaisemmin tekstissä mainittiin. Digitaalisten kaksosten ja virtuaalisten käyttöönottojen kehitys on työn alla. Jatkossa kehitetään osaprosessien yhdistämisen hallintaa ja osaprosessien välistä kommunikointia sekä tiedonkeruuta ja käsittelyä. Kyberturvallisuus ja NIS2-direktiivi ovat myös opetuksen aiheita, joita ei voida ohittaa, ja niiden tuominen käytännön esimerkkeinä opetukseen on tulevaisuuden tähtäimessä.

Lähteet:

Endress & Hauser 2025. Viitattu 7.3.2025.
<https://www.fi.endress.com/fi/tuotetiedot-nopeasti-k%C3%A4ytt%C3%B6%C3%B6si/operations-app-laitetiedot-nopeasti>

Etto, J., Majuri, M. & Sipola, J. 2023. Kunnossapidon opetusta uudistettiin Lapin AMK:ssa. Promaint 4/2023. Viitattu 7.3.2025.
<https://promaintlehti.fi/Lehtiarkisto/Promaint-4-2023>

Azwirman Gusrialdi*

Resilient Cooperative Control of Cyber-Physical Systems Under Cyber-Attacks

Keywords: Resilient control, cooperative control, cyber-attacks, distributed algorithm, safety-critical systems

*Corresponding Author: **Azwirman Gusrialdi**: Faculty of Engineering and Natural Sciences, Tampere University, E-mail: azwirman.gusrialdi@tuni.fi

1 Background

Cyber-physical systems (CPS) are the backbone of modern society, powering transformative applications such as smart grids, intelligent transportation systems, robotic networks, smart manufacturing, and smart buildings. These systems tightly integrate physical processes with cyber (e.g., computing, communication and networking) technologies, creating a vast network of interconnected devices. Cooperative control plays a crucial role in ensuring stability and optimizing performance of CPS. Specifically, the individual system collaboratively computes its control input to achieve a common/global goal through local communication and without centralized entity, thus enabling scalability, low latency, and robustness. However, the same network connectivity that facilitates these advantages also expands the attack surface, exposing vulnerabilities to cyber threats. These attacks compromise the confidentiality, integrity, and availability of data exchange, disrupting cooperative control mechanism and may result in physical damage as evidenced by the 2015 Ukraine power grid incident causing a 6-hour blackout. This calls for resilient cooperative control to ensure safe and optimal operation of CPS in presence of cyber-attacks. However, the design of resilient cooperative control against cyber-attacks is highly challenging due to the unpredictability of attack parameters, including their number, timing, duration, and location.

2 Aims

We present a resilient cooperative control algorithm that has been developed in our research group for the past ten years [1–3]. Specifically, the cooperative control algorithm ensures resilient operation of CPS against

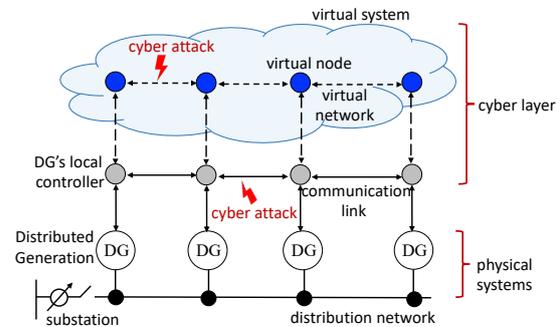


Fig. 1. Competitive interaction design featuring a virtual system interconnected with a local controller in a power system use case.

false data injection attacks, a prevalent form of deception attacks, which inject malicious signals into the communication links to alter exchanged data. The proposed method allows unlimited communication links/channel to be attacked while assuming a bounded attack magnitude, a reasonable precaution for intelligent attackers to avoid detection. The proposed cooperative control is independent of the networking technologies and also enables real-time attack detection and identification.

3 Materials and Methods

The resilient cooperative control algorithm is designed based on the competitive interaction design method proposed in the author's work [1–3]. This method introduces a virtual system consisting of virtual nodes, each maintaining a non-physically meaningful state variable (referred to as a virtual state), as illustrated in Fig. 1. These virtual nodes communicate through a virtual network, also susceptible to attacks, and interact with the local controllers of individual systems via an internal signal. This setup forms a competitive interaction. The virtual network can be implemented using cloud infrastructure or multiple communication channels, with the virtual states functioning as auxiliary states of the local dynamic controller. The dynamics of the virtual system is designed for ensuring convergence to a neighbourhood of normal operating point of the CPS, detecting attacks, and in the absence of attacks maintaining convergence to the normal operating point.

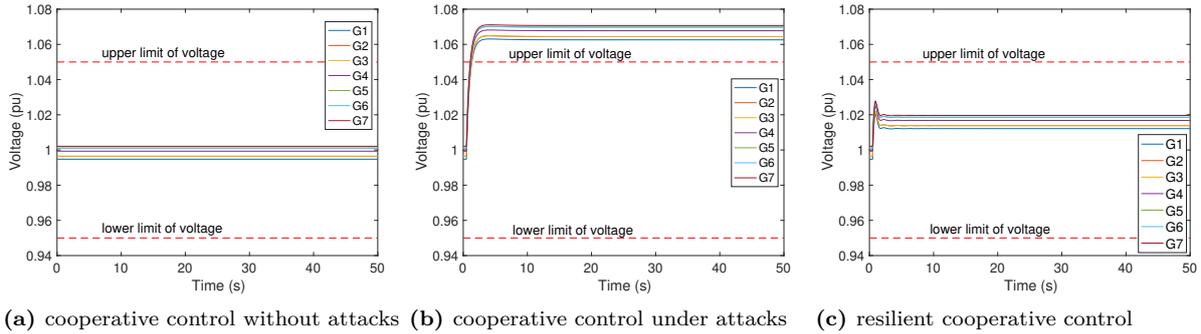


Fig. 2. Voltage profiles of PVs in a distribution network under three considered scenarios

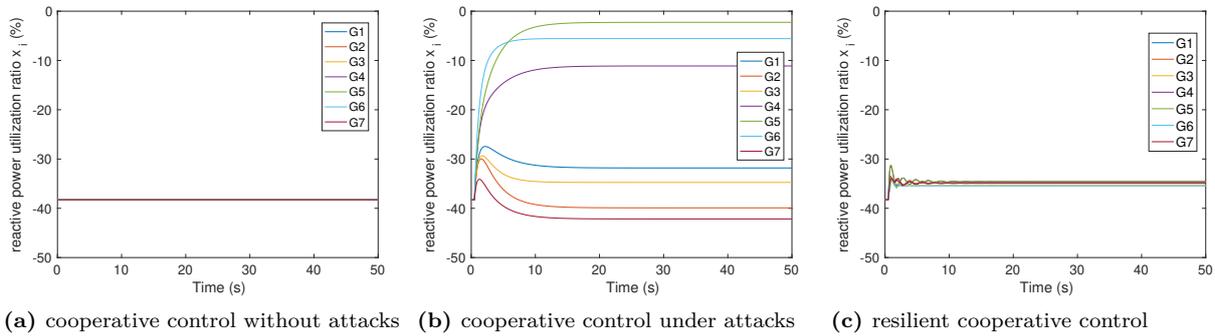


Fig. 3. Utilization ratios of DGs in a distribution network under three considered scenarios

4 Results

We demonstrate the resilient cooperative control on voltage control for a distribution network consisting of distributed generations such as photovoltaics (PVs). High penetration of PVs will cause several technical issues such as the over-voltage problem in the network which occurs mainly when PV generation reaches its peak while the load demand is relatively low. One possible strategy to mitigate the over-voltage issue is to implement a cooperative control algorithm at each PV to control and coordinate their reactive power in the network during this time. Decisions at the local level are made by each PV exchanging information via a communication network. The goal is to control the reactive power of the PVs such that the voltage deviation of all PV buses are well regulated within the ANSI standard limits (5%) in order to ensure power quality. An additional control design goal is to have reactive power load sharing where all the PVs contribute equally to the voltage control. Applying cooperative control algorithm designed in [4] ensure that the voltage of the PVs are within the safe operating limit and achieving equal reactive power utilization ratios as shown in Figs. 2a, 3a. Next, we introduce false data injection attacks on the

communication network. As shown in Figs. 2b, 3b, the attacks render overvoltage for all the PVs in the group and that their utilization ratios fail to reach a consensus. Finally, we implement the resilient cooperative voltage control developed in [4]. It can be observed from Fig. 2c that, due to the virtual network, the voltages of all the PVs are regulated and maintained within the operational limits even though some of the communication links are compromised. Furthermore, utilization ratios of all the PVs are also made to approach a consensus as evidenced from Fig. 3c.

References

- [1] Gusrialdi A, Qu Z, Simaan M. Robust design of cooperative systems against attacks. In: *Proceedings of American Control Conference*. 2014; pp. 1456–1462.
- [2] Gusrialdi A, Qu Z, Simaan MA. Competitive interaction design of cooperative systems against attacks. *IEEE Transactions on Automatic Control*. 2018;63(9):3159–3166.
- [3] Iqbal M, Qu Z, Gusrialdi A. Distributed resilient consensus on general digraphs under cyber-attacks. *European Journal of Control*. 2022;p. 100681.
- [4] Gusrialdi A, Xu Y, Qu Z, Simaan MA. Resilient cooperative voltage control for distribution network with high penetration distributed energy resources. In: *Proc. of European Control Conference*. 2020; pp. 1533–1539.

Antti Välimäki*, Outi Rask, David Hästbacka, Tero Hietanen, Manne Tervaskanto

Tekoälytutkimukseen liittyvän valmisteluhankkeen tuloksia

Tiivistelmä: AIKO-tekoälyhankkeen valmistelussa pidettiin kaksi työpajaa, joiden kaksi päätulosta esitellään tässä paperissa. Ensimmäiseksi käydään läpi osallistujille tehdyn kyselytutkimuksen sisältö, ja sen jälkeen esitellään työpajoissa pidettyjen yritysten esityksiä, joissa on kerrottu miten tekoälyä on sovellettu eri yrityksissä ja heidän asiakkaillansa.

Avainsanat: tekoäly, RAG, koneoppiminen, LLM, kielimalli

***Antti Välimäki:** Tampereen ammattikorkeakoulu, antti.valimaki@tuni.fi

Outi Rask: Tampereen ammattikorkeakoulu, outi.rask@tuni.fi

David Hästbacka: Tampereen yliopisto, david.hastbacka@tuni.fi

Tero Hietanen: Oulun ammattikorkeakoulu, tero.hietanen@oamk.fi

Manne Tervaskanto Oulun ammattikorkeakoulu, manne.tervaskanto@oamk.fi

1 Johdanto

Tampereen ammattikorkeakoulu (TAMK) haki rahoitusta tekoälyn ja automaatioon liittyvän hakemuksen valmisteluun Etelä-Savon ELY-keskukselta, joka myönsi rahoituksen vuoden 2024 alusta. Tämän pohjalta käynnistimme valmisteluhankkeen, jossa olivat mukana Oulun ja Tampereen ammattikorkeakoulut sekä Tampereen yliopisto. Tärkeimmät toimenpiteet olivat kahden työpajan järjestäminen uusimpien tekoälysovellusten ja -työkalujen esittelyyn, varsinaisen hakemuksen vaatimusten täyttämisen ja hakemuksen lähettäminen, joka sisälsi riittävän laajan ekosysteemin ja ulkoisen rahoituksen. Tässä paperissa esitellään sekä työpajojen yhteydessä tehtyjen kyselyjen tulokset että työpajojen esitysten keskeisimmät asiat.

2 Tutkimusasetelma

Tutkimuksen materiaali kerättiin yrityksiltä kolmessa eri vaiheessa seuraavasti:

- Yrityshaastattelut.** Tässä vaiheessa kontaktoitiin tekoälyn ja automaatio-suunnittelun parissa toimivia yrityksiä ja kerättiin tilannekuvaa heidän tämänhetkisistä toimenpiteistä asiassa. Keskusteluja käytiin yli 10 yrityksen kanssa tässä vaiheessa. Tätä tietoa hyödynnettiin sekä kyselytutkimuksen kysymysten asettelun että työpajojen sisältöjen suunnittelussa. Niitä tuloksia ei tässä artikkelissa käydä sen tarkemmin läpi.
- Työpajat:** Työpajoihin koottiin aiheesta kiinnostuneita yrityksiä keskustelemaan ja työstämään asiaa eteenpäin. Työpajoissa oli myös alustuspuheenvuoroja eri tyyppisistä automaatio- tai tekoälyalaan liittyvistä yrityksistä. Työpajoja järjestettiin 2 ja niihin osallistui yhteensä 56 osallistujaa 31 eri yrityksestä. Tulokset on esitelty tämän artikkelin luvussa 3.
- Kyselytutkimus:** Kyselyä jaettiin vielä laajemmalle osallistujakunnalle mm. välittämällä sitä suorilla yrityskontakteilla Tampereen ja Oulun alueella sekä LinkedInissa. Kysely lähetettiin myös työpajoihin ilmoittautuneille henkilöille sähköpostilla ennen työpajoja. Kyselyyn vastasi 21 eri yritystä, joista 3 oli mikroyrityksiä, 11 pk-yrityksiä ja 7 suuryrityksiä. Vastausten määrä ei ole riittävä kovinkaan kattavaan analyysiin, mutta suuntaviivoja sen ja muiden materiaalien pohjalta voidaan kyllä vedellä. Tulokset on esitelty tämän artikkelin luvussa 4.

3 Työpajojen tuloksia

Työpajat järjestettiin 25.4.2024 ja 6.6.2024 hybridimuotoisena, ja ne toteutettiin TAMKin seminaarihuoneessa sekä Teams-työkalulla. Työpajoissa oli pitämässä esityksiä kuusi eri tekoälyä

soveltavaa yritystä, joiden esitysten pohjalta saatiin hyvä kuva tekoälyn tilanteesta eri yrityksissä.

Tekoäly on yhä tärkeämmässä roolissa teollisuuden automaatiassa. Esityksissä korostettiin, että tekoälyä voidaan hyödyntää monin eri tavoin tehtaiden prosessien optimoinnissa ja tuotannon tehostamisessa.

Tekoälyä sovelletaan yrityksissä usein joko koneoppimis- tai generatiivisen tekoälyn työkaluilla ja menetelmillä. Erään esityksen mukaan tekoälysovelluksista tehdään noin 70 % koneoppimissovelluksina ja loput generatiivisina tekoälysovelluksina, mutta nämä suhteet ovat hyvin yritys- ja toimittajakohtaisia. Toimittajilla voi olla käytössä valmiita työkaluja sovellusten nopeampaan kehittämiseen tai toisena vaihtoehtona voidaan räätälöidä yksityiskohtaisempi sovellus, jos valmiiden työkalujen ominaisuudet eivät riitä.

Esimerkiksi koneoppimismallit voivat opastaa operaattoreita tekemään parempia päätöksiä, mikä parantaa tuotteen saantoa ja tuottoa. Esimerkkinä esiteltiin tapaus, jossa tehostettiin kalanrehun valmistusta opastamalla operaattoreita ohjaamaan panosprosessia neuroverkko-pohjaisen tekoälyn ehdottamien operointisuureiden avulla. Oleellista on, että operaattori tekee lopulliset päätökset koneoppimissovelluksen ehdotusten tai oman asiantuntemuksensa pohjalta. Tässä esimerkissä lopputuloksena tuotteen saanto ja tuotto saatiin nostettua tasolle, joka vastasi kehitystyölle asetettuja vaatimuksia.

Koneoppiminen tarjoaa monia mahdollisuuksia teollisuuden eri osa-alueilla. Esityksissä esiteltiin eri tapoja tehdä tekoälysovelluksia sekä niiden toiminnallisuutta joko lähellä varsinaista PLC-sovellusta, pilviratkaisuna tai näiden välimuotona. Tavoitteena on luoda työkalut, joilla automaatiosuunnittelija voi itsenäisesti kehittää koneoppimissovelluksia.

Koneoppimisen sovelluskohteita ovat esimerkiksi laadunvarmistus, jossa halutaan parantaa tuotteen laatua ja vähentää virheitä. Muita kohteita ovat hukan vähentäminen optimoimalla prosesseja, jotta raaka-aineiden hukka minimoidaan. Robottien integroinnissa tehostetaan tuotantoprosesseja. Näiden lisäksi ennustavassa ylläpidossa ennakoitaan laitteiden huoltotarpeet ja vähennetään seisokkiaikoja.

Koneoppimissovelluksissa on tyypillisesti kolme pilaria: laboratorio-, asiakas- ja ground truth -pilarit (totuuden lähde). Laboratorioissa tekoälymalli luodaan ja koulutetaan asiakasdatalla, ja mallin parametreja optimoidaan parhaan tarkkuuden saavuttamiseksi.

Haasteena on, että laboratoriossa saavutettu sovellus ei aina täysin vastaa todellista tuotantoympäristöä. Asiakaspilarissa mallia käytetään ja sovelletaan tosielämän tarpeisiin ja ympäristöihin sekä kerätään palautetta siitä, miten hyvin mallin vastaukset vastaavat asiakkaiden tarpeita. Ground truth -pilarissa kerätään esimerkiksi oikeita vastauksia, joita käytetään mallin uudelleen koulutukseen, kun dataa kertyy lisää.

Generatiivista tekoälyä voidaan soveltaa esimerkiksi automaatiosuunnittelun tehostamiseen käyttämällä erilaisia kielimalleja, joiden avulla voidaan integroida ChatGPT:n kaltaisia työkaluja työskentelyn avuksi. Näillä työkaluilla suunnittelutyötä voidaan tehostaa esimerkiksi generoimalla alustavia ohjelmia sekä PLC-että käyttöliittymäsovelluksille, lisäämällä kommentteja nykyisiin sovelluksiin ja vastaamalla suunnittelijan kysymyksiin liittyen sovellusten tekoon.

Generatiivinen tekoäly tarjoaa myös uusia mahdollisuuksia erityisesti asiakaspalvelussa ja tuottavuuden parantamisessa. Sovelluskohteina voivat olla esimerkiksi asiakaspalvelu, jossa LLM-pohjaiset ratkaisut voivat vastata asiakkaiden kysymyksiin etukäteen tarkastetuilla vastauksilla, mikä vähentää hallusinoitio ongelmia. Sovellus voi auttaa myös liiketoimintamahdollisuuksien tunnistamisessa sekä dokumenttien käsittelyssä, jolloin tarkistetaan dokumentin kirjoitusmuotoa, käännetään teksti eri kielelle tai muut dokumenttien automaattiset käsittelyt.

Kielimalli eli LLM-työkaluilla on kuitenkin omat riskinsä, kuten hallusinoitio ongelmat. Tämän vuoksi on tärkeää rajoittaa vastauksia ja varmistaa niiden oikeellisuus. LLM-ratkaisuissa on yleistä toteuttaa sovellus Retrieval Augmented Generation (RAG) -tyyppisenä, jossa yhdistetään yrityksen oma dokumenttien tietokanta ja muut vastaavat tietolähteet sekä LLM-työkalun kyvyt.

Tekoäly-sovellusten kehittäminen kannattaa aloittaa pienistä sovelluksista, joissa takaisinmaksu on nopeampaa. Asiakas on keskeisessä roolissa, kun valitaan käyttötapaukset ja oikea tekniikka tavoitteen saavuttamiseksi. Sovellusten kehittämistyökalut valitaan tyypillisesti projektikohtaisesti, esimerkiksi Azuren, Google Cloudin, Amazonin tai Tableaun tarjonnasta tai yrityksen omista tekoäly-työkaluista.

Eräissä esityksissä korostettiin tekniikan kehittymisen nopeutta ja käytiin läpi erilaisia asiakasprojekteja. Esityksessä kuvattiin myös, miten työntekijöille on hyödyllistä käyttää esimerkiksi ChatGPT:tä ja Microsoftin Copilot-työkaluja henkilökohtaisella tasolla. Lisäksi esiteltiin yritykselle kehitettyjä työkaluja, joissa on hyödynnetty esimerkiksi Azurea, Googlea ja OpenAI:n välineitä. Yrityksen sisäisen

toiminnan tehostamisessa käytetään muun muassa SAP-, Salesforce- ja M-Files-dokumenttien hallintavälineitä, jotka sisältävät tekoälyominaisuuksia. Yritystasolla hyödynnetään myös RAG-pohjaisia ja koneoppimisovelluksia. Yrityksille voidaan lisäksi kehittää räätälöityjä AI-sovelluksia esimerkiksi prosessien optimointiin ja ennustamiseen. Tuotetasolla asiakkaille voidaan tarjota älykkäitä huoltopalveluja, jotka ennustavat asiakkaan prosessien toimintaa. Tuotekehityksessä voidaan luoda erilaisia asiakastuotteita, jotka sisältävät räätälöityjä tekoälysovelluksia.

4 Kyselytutkimuksen tulokset

Kyselytutkimukseen osallistui 21 henkilöä yhtä monesta yrityksestä. Yritykset edustivat sekä automaatiosuunnittelua tuottavaa yritystoimintaa että tekoälypalveluita yleisemmin tuottavaa liiketoimintaa. Näissä tuloksissa ei ole huomioitu muista tiedonkeruulähteistä (työpajat tai yrityskohtaiset haastattelut) kerättyjä tuloksia vaan keskitytään ainoastaan kyselytutkimuksen tuloksiin.

Kyselyssä kysyttiin seuraavia asioita:

1. Miten tällä hetkellä teidän yrityksessänne käytetään tekoälyä liiketoiminnassa?
2. Miten tällä hetkellä teidän yrityksessänne käytetään tekoälyä automaatiosuunnittelussa ja muissa suunnittelutehtävissä?
3. Mitä ja millaisia tekoälytuotteita tai – palveluita teillä tällä hetkellä on tuotevalikoimassanne?
4. Miten arvioisit tekoälyn hyödyntämisen muuttuvan /kehittyvän seuraavan 5 vuoden aikana mm. Tuotteiden, palveluiden ja suunnittelumenetelmien yhteydessä tai niiden kehittämisessä?
5. Millaisista tekoälyyn liittyvistä sovelluksista voisi olla hyötyä yrityksenne sisäisessä toiminnassa

Vastauksista tehtiin kevyt sisällönanalyysi jaotteleamalla vastauksia isompiin teemakokonaisuuksiin seuraavasti: 1) suunnittelutehtävät, 2) dokumentointi, 3) data-analyysi, 4) kuvat ja piirroukset, 5) työskentelyprosessit, 6) myynti, markkinointi ja kirjanpito, 7) asiakastoimitukset ja 8) ongelmanratkaisu. Tulokset on esitetty näiden kategorioiden mukaisesti.

Tällä hetkellä kyselyyn vastanneissa yrityksissä tekoälyä sovelletaan yleisemmin liiketoiminnassa tai suunnittelutehtävissä seuraavasti (kysymykset 1 ja 2):

1. **Suunnittelutehtävät.** Päälimmäisenä tässä nousi esille ohjelmointitehtävät, joissa tekoälyä käytetään ohjelmoinnissa ja se aputyökaluina. Konkreettisenä ohjelmointikohteena mainittiin mm. PC-valvomoiden ohjelmointi ja konenäkösovellukset. Myös laadunvalvontaan liittyvät tehtävät mainittiin.
2. **Dokumentointi.** Jonkin verran tällä hetkellä tekoälyä hyödynnetään raportoinnissa ja dokumenttipohjien luonnissa. Lisäksi dokumenttien kääntämiseen käytetään tekoälyä. Jotkut tuottivat tekoälyn avulla myös suunnitteluohjeita suunnittelutyökaluihin.
3. **Data-analyysi.** Tekoälyä käytettiin jossain määrin tiedon analysointiin ja kategorisointiin sekä ennustemallien laadintaan. Nämä vastaukset nousivat esille liiketoimintakysymyksen (kysymys 1) yhteydessä, joten oletamme, että tämä ei liity suunnittelutehtävissä syntyvän datan vaan liiketoimintaprosesseista saatavan datan analysointiin.
4. **Kuvat ja piirroukset.** Kuvia tehtiin tällä hetkellä lähinnä kuvituskuviksi tekoälyn avulla myynnin ja markkinoinnin tarpeisiin.
5. **Työskentelyprosessit.** Sisäisen toiminnan tehostamiseen ja mm. Suunnitteluohjeistuksen laatimiseen tekoälyä sovelletaan tällä hetkellä.
6. **Myynti, markkinointi ja kirjanpito.** Myynnissä ja markkinoinnissa tekoälyä hyödynnettiin ehkä laajimmin tällä hetkellä. Mainittiin mm. sosiaalisen median postausten ja kuvituskuvien tekeminen konkreettisina toimintoina.
7. **Asiakastoimitukset.** Asiakkaille tehdään tällä hetkellä jonkin verran jo tekoälyä soveltavia ratkaisuita. Vastauksista ei selviä mitä nämä asiakkaat tarkemmin ottaen ovat, joten arvoitukseksi jäi, tarkoitetaanko asiakkaalla tässä esimerkiksi automaatiosuunnittelua tekeviä toimijoita.
8. **Ongelmanratkaisu.** Tähän kategoriaan liittyviä sovelluksia ei noussut tuloksissa esille.

Käytössä olevia konkreettisia työkaluja kysyttäessä (kysymys 3) vastaus oli melko suppea. Suurimmalla osalla ei ollut käytössä mitään tiettyä työkalua ja muutamissa vastauksissa nousi esille yleisesti käytössä oleva generatiivisen AI:n työkalu Microsoft Copilot. Lisäksi mainittiin yleisemmin GenAI -työkalut.

Kysymyksessä 4 visioitiin, millaisissa tehtävissä tekoälysovellusten käytön arvellaan lisääntyvän seuraavan 5 vuoden aikana. Tässä on käytetty samaa jaottelua kuin aikaisemmassa kohdassa, jotta vastauksia on helpompi vertailla nykyhetken ja tulevaisuuden näkymien välillä.

1. **Suunnittelutehtävät.** Ohjelmoinnissa nähdään tekoälyn roolin kasvavan merkittävästi seuraavien vuosien aikana. Sitä arvellaan käytettävän enenemissä määrin ohjelmointikomponenttien luonnissa ja ylipäättään kaikessa ohjelmoinnissa ja niiden testauksessa. Oletetaan, että suunnittelutehtävissä yleisemminkin tekoäly tulee poistamaan manuaalista työtä. Arvellaan jopa, että AI saattaisi korvata yksinkertaisempaa logiikkaa.
2. **Dokumentointi.** Dokumentoinnissa selkeä lisäys tai muutos nykyhetken vastausten mukaan olisi se, että suunnitteluohjeistukset suunnittelutyökaluissa muuttuisivat entistä enemmän chat-avusteisiksi.
3. **Data-analyysi.** Tätä kohtaa ei yllätyksekseni erikseen mainittu näissä vastauksissa.
4. **Kuvat ja piirrokset.** Tekoälyavusteisen piirustustuotannon lisääntyminen on vastausten mukaan odotettavissa. Näillä tarkoitetaan nimenomaan suunnitteludokumentaatioon liittyviä piirustuksia.
5. **Työskentelyprosessit.** Näihin liittyen odotetaan tekoälyn muuttavan ihmisten ajattelua sekä parantavan työhyvinvointia. Lisäksi suunnittelumenetelmien kehittämisessä yleisemmällä tasolla odotetaan tekoälyn tuovan muutosta tulevien lähivuosien aikana.
6. **Myynti, markkinointi ja kirjanpito.** Tässä kategoriassa erityisesti tarjouslaskentaan liittyvien sovellusten nähtiin tulevan toimintaan mukaan. Lisäksi kirjanpidon tehtävissä tekoälysovellusten odotetaan ottavan lähivuosina isompaa roolia.
7. **Asiakastoimitukset.** Näihin odotetaan merkittävää palvelutarjonnan lisääntymistä tulevina vuosina.
8. **Ongelmanratkaisu.** Ongelmanratkaisun apuvälineenä tekoälyä myös uskottiin tulevan mukaan lähivuosina.

Yleisesti 5 vuoden kuluessa uskotaan, että tekoälysovellusten lisääntyminen suunnittelualoilla

toimivien yritysten toiminnassa tulee olemaan eksponentiaalisesti kasvavaa. Yksinkertaisten ja toistuvien asioiden toteuttamiseen uskotaan tekoälystä olevan erityisesti hyötyä ja uusien toimialojen uskotaan liittyvän tekoälyä soveltavan toiminnan hyödyntäjien joukkoon. Muutosvistarintaa löytyy ja se on varmasti aiheellistakin pohdintaa monissa yrityksissä, mutta vastausten perusteella näytettäisiin kuitenkin uskovan, että nyt meneillä oleva muutos on vääjäämättä etenemässä ja tekoälyn soveltaminen työelämässä tulee lisääntymään joka tapauksessa.

Viimeinen teema (kysymys 5) johdatteli vastaajia pohtimaan asiaa enemmän siitä näkökulmasta, millaiset tekoälysovellukset auttaisivat juuri häntä itseään ja omaa yritystään sisäisessä toiminnassa.

1. **Suunnittelutehtävät.** Toiveissa ja tarpeissa nousi tässä kohdassa vahvasti esille ohjelmoinnin, koodin generoinnin ja ohjelmien testauksen apuvälineet. Tekoälyn toivotaan tulevan hyödyntämään ohjelmistosuunnittelua yleisemminkin.
2. **Dokumentointi.** Tekoälysovellusten toivotaan tuovan lisää hyötyä ja tehokkuutta myös raportointiin tulevaisuudessa. Lisäksi hyödylliseksi koetaan tekoälyn soveltaminen tiedonhaussa, yksinkertaisten dokumenttien luomisessa sekä dokumenttien tarkastuksissa ja laajempien dokumenttien yhteenvetojen tuottamisessa.
3. **Data-analyysi.** Yleisesti tekoälyn toivotaan tulevan avuksi datan analysoinnissa, ennusteiden laatimisessa datan pohjalta, datan kategorisoinnissa ja kuvantunnistukseen liittyvissä tehtävissä.
4. **Kuvat ja piirrokset.** Kvanttunnistus mainittiinkin jo edellisessä kohdassa, mutta se sopisi yhtä hyvin myös tähän kohtaan. Lisäksi tekoälyn toivotaan tuovan apuja piirustusten tuotantoon ja niiden tarkistamiseen.
5. **Työskentelyprosessit.** Erityisen hyödylliseksi todettiin tekoälyyn pohjautuvat työkalut, joilla saadaan joko ajanhallintaa tehostettua tai sitten poistettua nyt manuaalisesti tehtävää työtä. Näin tekoälyn uskotaan tuovan lisää työhyvinvointia, kun resurssia vapautuu muihin suunnittelutehtäviin.
6. **Myynti, markkinointi ja kirjanpito.** Laajemmin tekoälysovellusten uskotaan tuovan helpotusta myyntiin ja markkinointiin liittyviin tehtäviin. Erityisesti insinööriyöhön liittyvissä

tehtävissä tässä osuudessa tekoälysovelluksia toivotaan tarjoustentekoprosessien automatisointiin.

7. **Asiakastoimitukset.** Näitä ei noussut tässä kysymyksen kohdalla esille. Se johtunee kysymyksen asettelusta (kysyttiin sisäiseen toimintaan liittyviä toimintoja).
8. **Ongelmanratkaisu.** Tähänkään liittyviä asioita ei noussut esille. Uskaltaisiko tästä vetää sellaisen hataran johtopäätöksen, että päättelyyn ja ongelmanratkaisuun liittyviä teemoja joko pidetään vielä liian vaikeina tekoälylle tai niin ihmismielelle mielekkäinä tehtävinä, että ne halutaan pitää ihmisten ratkaistavina jatkossakin? Siitäkin huolimatta, että se kuitenkin kysymyksen 4 kohdalla tätä asiaa hieman nostettiin esiin.

5 Yhteenvedo tekoälyn mahdollisuudet automaatiassa

Tekoäly tarjoaa lukuisia keinoja kehittää automaatiota eri tasoilla. Tärkeää on kuitenkin valita tehtävään soveltuvat työkalut ja menetelmät. Aina tekoälysovellus ei ole paras tapa ratkaista ongelma, vaan perinteisillä ohjelmistoilla päästään edelleen pitkälle.

6 Jatkotoimenpiteet

AIKO-tekoäly-valmisteluhanke päättyi vuoden 2024 kesäkuun lopulla, jonka jälkeen aloitettiin varsinaisten hakemusten teko Tampereen yliopiston, Oulun ja Tampereen ammattikorkeakoulujen toimesta. Jatkohankkeet ovat kunkin tutkimuslaitoksen omia, mutta niiden välillä pyritään luomaan hyvä koordinaatio, jotta voidaan hyödyntää eri osapuolten osaamista nyt ja tulevaisuudessa. Jatkohankkeet menivätkin läpi, jolloin tekoälyn tutkimus automaatiassa jatkuu vuosina 2025-2026.

Antti Ranta*, Teijo Juntunen, Alex Kanerva, Matti Vilkkö, Sami Repo, and David Hästbacka

Comparison of Integration Architectures for Process Flexibility in Industrial Processes

Abstract: This paper introduces a software systems architecture and design for an industrial process and its supporting subsystems and components. Material is based on two energy-intensive industrial (EII) use cases: 1) a wastewater treatment plant (WWTP) and 2) a glass manufacturing plant. Both systems include similar components from external partners. Many of these external components are related to energy optimization. A general design based on the use cases is proposed. Decentralization and loose coupling of components are key properties of the suggested design. The proposed design is then compared to the emergent design of the use cases. The deployment and integration of a single component, a process optimization agent (PoA), which adheres to the proposed design, is then explained.

Keywords: energy flexibility, integration, software deployment

***Corresponding Author: Antti Ranta:** Tampere University, E-Mail: antti.ranta@tuni.fi

Teijo Juntunen: Tampere University, E-mail: teijo.juntunen@tuni.fi

Alex Kanerva: Tampere University, E-mail: alex.kanerva@tuni.fi

Matti Vilkkö: Tampere University, E-mail: matti.vilkkö@tuni.fi

Sami Repo: Tampere University, E-mail: sami.repo@tuni.fi

David Hästbacka: Tampere University, E-mail: david.hastbacka@tuni.fi

1 Background

The global transition to green energy is changing the energy industry. For example, the European Union has taken a leading role in minimizing carbon emissions [1]. These decarbonization goals for the energy industry have led to a diversification of energy sources in industrial processes. As a result, the electrification of industrial processes is increasing. Increasing electricity demand and intermittent renewable energy generation are reflected as price volatility in the electricity markets. These changes introduce potential for optimization of energy usage. One specific optimization area is the concept of energy flexibility. For example, it may be economically beneficial to consume energy only at a specific time of the day depending on the inherent prop-

erties of an industrial process itself and the state of the energy markets and grid requirements.

Additionally, the transition to Industry 4.0 introduces more fine-grained methods and opportunities for optimization. Compared to traditional hierarchical and isolated models of industrial control systems (ICS), the shift towards more intelligent and connected devices enables more detailed optimization of energy usage. For example, a digital twin (DT) could provide real-time data on the energy consumption of an industrial process to other stake holders, who can then utilize this data for optimization models.

On a higher level, both the decarbonization and Industry 4.0 transitions can be seen as the initial phases toward flexible, loosely coupled, and decentralized energy markets. Such markets could allow energy consumers and producers to participate in broader energy markets where stakeholders could be located in different geographical regions. In these markets, purchasing different energy products would be easy, reliable, and economically and environmentally beneficial. For example, decisions to trade different energy products could be based on optimization calculations. These include calculations such as energy consumption, cost optimum calculations and flexibility potential calculations.

2 Aims

On a general level, the objective of this paper is to explore what kind of software system architecture and design would be suitable for a decentralized and loosely coupled energy system. Examples of participants in such a system could be energy consumers and producers, energy market predictors, energy management systems, energy optimization models, and decision support systems. The emphasis of this paper is on identifying the software system integration paradigms, design principles, communication protocols, software stacks, and security models that would be appropriate for such a system.

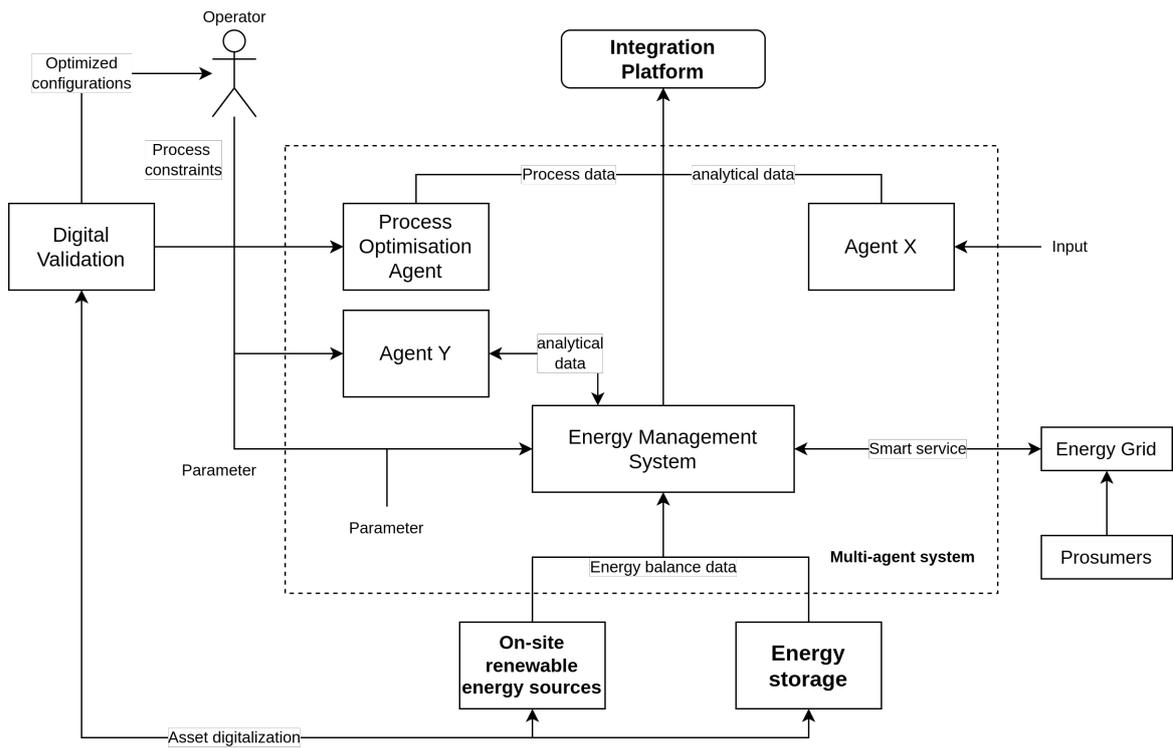


Fig. 1. High-level overview of integration platform based on use cases

3 Materials and Methods

The work in this paper is based on two use cases of energy-intensive industries in the European Union member states. First use case is wastewater treatment plant. Second use case is glass manufacturing. First, a general overview of the desirable properties of a decentralized and loosely coupled energy systems are discussed based on the aforementioned use cases. After this analysis, a suggestion for an architectural design is introduced and its advantages and disadvantages are reviewed. The proposed system is based on the OPC UA PubSub standard [2]. A high-level overview of the different participants, systems and components based on the two use cases is depicted in figure 1.

Then an analysis of the real systems of the use cases is presented and analyzed. The use cases did not have a formal architecture in place beforehand. In other words, the design of the systems emerged during the deployment and integration phases of the components by the different participants.

A comparison of the suggested design with the emergent design of the use cases is then provided. This comparison is valuable, because one of the goals of a decentralized and loosely coupled architecture is to see

how a subsystem or a component can be integrated into a system of different design.

One of the key components that is integrated into the environments of the use cases is a process optimization agent. This component relies on flexibility calculations. However, the theoretical background of flexibility is out of scope of this paper. A general framework for the quantification of flexibility in industrial processes is presented in a related paper [3]. On the concept of flexibility itself and identifying flexibility potentials, there is another related paper [4].

Acknowledgement

This project has received funding from the European Union’s Horizon EUROPE research and innovation programme under Grant Agreement No 101058174 “TRINEFLEX”.

References

[1] Climate Action.

URL https://commission.europa.eu/publications/management-plan-2023-climate-action_en

- [2] OPC Foundation. OPC Unified Architecture - Part 14: Pub-Sub. *Tech. rep.* 2023.
URL <https://reference.opcfoundation.org/Core/Part14/v105/docs/>
- [3] Juntunen T. Framework for the Quantification of the Process Flexibility in Industrial Processes. 2025. Extended abstract for Automaatiopäivät 2025.
- [4] Kanerva A. Defining Energy Flexibility for Energy-intensive Industrial Processes. 2025. Extended abstract for Automaatiopäivät 2025.

Jouni Aro*, Luukas Lusetti, Elias Nykänen

Role-Based Security Management for Industrial Devices and Applications Based on OPC UA

Abstract: Open Platform Communications Unified Architecture (OPC UA, IEC 62541) has become a leading communication framework in industrial automation. OPC UA defines secure communication and information exchange that enable standardized connectivity between industrial applications in process monitoring, production control, manufacturing execution, etc.

In this paper we define a model for centralized security management for all industrial devices and applications, including user management and role-based access control (RBAC).

Keywords: OPC UA, security, RBAC, zones, IT/OT

***Corresponding Author: Jouni Aro:** Prosys OPC Ltd, E-mail: jouni.aro@prosysopc.com

Luukas Lusetti, Elias Nykänen: Prosys OPC Ltd, E-mail: luukas.lusetti@prosysopc.com, elias.nykanen@prosysopc.com

1 Background

Modern manufacturing sites use a varying number of smart devices and applications that are used to control the production on different levels. These applications are installed in different locations and networks within the factory. Some systems are located in IT networks that are connected to the Internet and others in OT networks that are more isolated from the Internet.

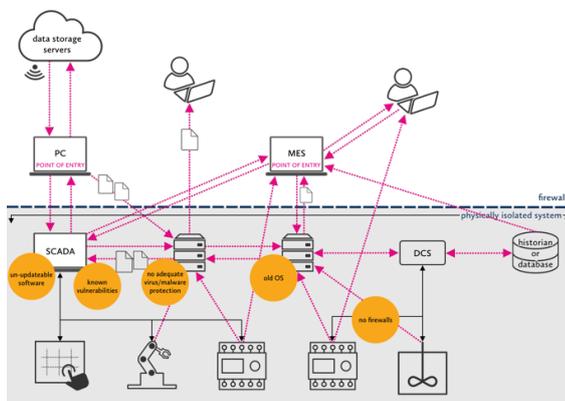


Figure 1. Typical connections across networks in a manufacturing site.

As the production processes get smarter, the IT and OT networks get more tightly connected, since more applications and systems in different networks are installed and they need more connections with each other. As a result, manufacturing networks are typically having many point-to-point connections going across the networks. Over time, this makes it tedious to manage the overall security of the manufacturing site, as shown in Figure 1.

OPC Unified Architecture (OPC UA) [1] enables standard data and information exchange between industrial applications using secure transport level communication [2,3,4].

OPC UA includes high level of security features, including message encryption to ensure confidentiality, integrity and availability of communications. Security is based on reliable authentication, which requires secure management of application and user identities. Authorization can then be applied to different server functionality, based on role-based access control (RBAC) [5].

OPC UA also defines a concept called Global Discovery Server (GDS) [6], which acts as an application registry, but also as a centralized certificate and user management application. OPC UA specification defines how applications can access the services provided by the GDS.

2 Aims

The aim is to present a model for managing application and user identities centrally with optional connections to existing IT network and user management systems via LDAP/AD connections.

The system also enables simple role-based access control (RBAC) based on roles defined in the central management system.

The roles can then be used in the server applications to limit access to critical functionality, such as controlling the devices, or even just to monitor their state.

3 Methods

OPC UA provides all tools necessary to organize secure information exchange between various systems in a manufacturing site. We can use a concept called Aggregation Server to define an application that collects connections to all data sources in a network and provides a single-point-of-access to higher level applications. If this application sits between the OT and IT network, it can also act as a central gate-keeper to all communications between these networks as shown in Figure 2.

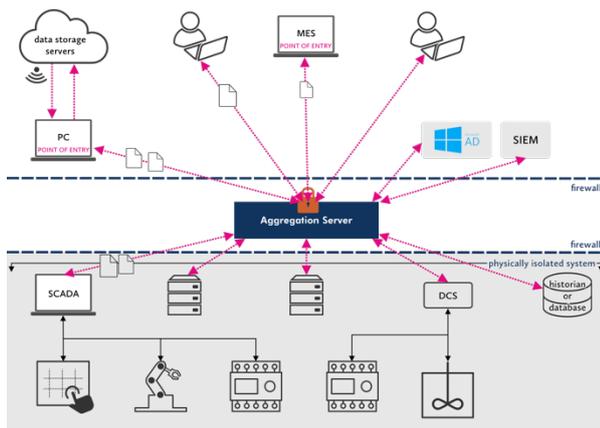


Figure 2. Centralized connections between IT and OT networks.

The Aggregation Server (AS) can include different functionality regarding data and information transformations, but here we concentrate solely on *security controls*. These include:

1. Confidentiality and integrity for data exchange
2. Access control between devices and applications
3. Centralized identity management for applications and users
4. Audit logging of actions

Typically, AS should sit in a De-Militarized Zone (DMZ), which is a separate network between the IT and OT networks, guarded from both sides with a firewall that restricts traffic to the AS only.

In addition to using an AS between the IT and OT networks, a separate AS can be used between all networks boundaries. It can be seen as a context sensitive firewall, even when no DMZ is used between the networks, if the firewall on either side restricts traffic to and from the AS only. ISA/IEC 62443 specifically defines zones and conduits [7] for improved security, and these are in practice implemented with separate networks that are connected to each other with highly restricted firewalls.

In addition to enforcing connections between networks to go via AS, connections between all applications can be enforced to go via AS. In this case, all communication can be monitored and controlled from AS. This can be especially useful, when legacy devices and applications lack specific security features. Using AS in between all communications ensures that all communications will use all necessary security controls.

(1) is applied by enforcing message signing and encryption on all communications, by limiting the available OPC UA Security Modes [2, 4.8] in AS.

(2) is applied by aggregating data and functionality in AS and applying access control measures based on the authenticated applications and users that are accessing specific data and functionality via AS.

(3a) is applied by enforcing all connections via AS and limiting access according to the applications and users identified by AS.

(3b) alternatively, AS can manage the access control lists of the aggregated data sources. This requires that they are OPC UA data sources and that they support this kind of external management as defined in OPC UA specifications [6].

(4) is applied by enforcing all operations via AS, in which case it can also ensure proper audit logging for all communication.

4 Bibliography

- [1] OPC 10000-1 (2024). OPC Unified Architecture Specification Part 1: Overview and Concepts v.1.05.04. OPC Foundation.
- [2] OPC 10000-2 (2024). OPC Unified Architecture Specification Part 2: Security v.1.05.04. OPC Foundation.
- [3] OPC 10000-6 (2024). OPC Unified Architecture Specification Part 6: Mappings v.1.05.04. OPC Foundation.
- [4] OPC 10000-14 (2024). OPC Unified Architecture Specification Part 14: PubSub v.1.05.04. OPC Foundation.
- [5] OPC 10000-18 (2024). OPC Unified Architecture Specification Part 18: Role-Based Security v.1.05.04. OPC Foundation.
- [6] OPC 10000-12 (2024). OPC Unified Architecture Specification Part 12: Discovery and Global Services v.1.05.04. OPC Foundation
- [7] ISA/IEC-62443-3-2:2020 Security for Industrial Automation and Control Systems, Part 3-2: Security Risk Assessment for System Design.

Automaatiopäivät 2025

Author: Lasse Linnamaa

Subject: Challenges of the changing power system and the role of automation and control in solving them – Fingrid's perspective

Abstract:

The role of grid automation and control technology in managing the electricity system is becoming more prominent. The operation of inverter-based resources (IBRs), such as wind and solar power, is based on manufacturer-specific programmable technology and is not described by physical equations like synchronous machines used in traditional power generation. This causes phenomena and interactions between plants that have not been seen before and need to be anticipated at the system level. For example, new kind of converter-driven or oscillatory stability problems can endanger the stability of the power system at times. However, the change also opens up new opportunities: with appropriate plant level control design and system level automation, these devices can be used efficiently to stabilize the power system, for example, in disturbance situations. This presentation will share Fingrid's view and future perspective as the TSO (transmission system operator) of Finland on the current status and challenges on the topic.

Timo Malm*, Taru Hakanen, Josepha Berger and Sami Karadeniz

Uncertain information related to situational awareness of mixed fleet and AMR - Safety perspective

Abstract: Situational awareness is a key to enable safe mixed fleet or AMR (automated mobile robot) and manual operations in situations where uncertain information is the puzzling factor. Uncertain information may be used sometimes, when reliable information is not available, for example due to limited Performance Level (PL), disturbances, environment, or poor visibility. The question here is, can uncertain information be applied for safety purposes. Safety must not be jeopardized. Case specific risk assessment is needed to ensure safety. Safety measures based on uncertain information may be acceptable if they are limited to specific conditions, such as a defined time frame, reduced speed, controlled distance, adequate visibility, or a particular mode of operation.

Keywords: uncertainty, autonomous mobile machine, AGV, AMR, mixed fleet

***Corresponding Author: Timo Malm:** VTT, Finland,
E-mail: timo.malm@vtt.fi

Taru Hakanen: VTT, Finland,
E-mail: taru.hakanen@vtt.fi

Josepha Berger: VTT, Germany,
E-mail: josepha.berger@vtt.fi

1 Background

New Machine regulation (EU) 2023/1230 [1] describes autonomous mobile machinery and related basic requirements. According to the regulation the collision avoidance system is based on either peripheral protection system or on-board devices intended to detect human or any other obstacle in its vicinity to avoid collisions. The peripheral protection system is typically related to fleet management, which is capable to control access into parts of the system to avoid collisions. On-board protection system forms a situational awareness area beside the mobile machine to maintain safe distance to obstacles. Situational awareness is defined as “the perception of the elements in the environment within a volume of time

and space, the comprehension of their meaning and the projection of their status in the near future” [2]. In MixedFleet project the original definition remains the same, but we apply the concept on mixed fleets including both M2H (Machine-to-Human) and M2M (Machine-to-Machine) perspectives [3]. Situational awareness refers typically in on-board systems to the mobile machine and in peripheral protection systems to fleet management. Situational awareness can be also dynamic so that it depends for example, the phase of the process or the traffic density. Situational awareness can be related also to persons (M2H), which means that a person receives information and forms his own situational awareness notion. All these different situational awarenesses are related to safety.

Situational awareness can be based on e.g. reliable information gathered from sensors and safety PLCs having adequate (safety) Performance Level (PL) and applied according to device manual, or e.g. uncertain information based on e.g. information from sensors having inadequate PL, inadequate physical capability (e.g. detection range), information is not up to date, or the information contains errors.

2 Aims and methodology

The aim or question here is, how uncertain information can be applied for safety purposes.

The method is here first to get information from interviews, group discussions, standards, and literature. Then the gathered ideas related to uncertainty have been tested with researchers and with designers. Finally, the conclusions are made from the gathered material.

3 Results

Uncertain information is applied sometimes in the industry. Uncertainty is more common in outdoor environment, where rain, fog or snow may reduce visibility remarkably. The focus is here on indoor applications, but some examples are related to outdoors use.

Situational awareness refers here to mixed fleets, including AMRs, and manual machines, which all are

capable to model their environment to avoid collisions. This is related to detection of objects, adequate separation distance, and concluding results with adequate safety logic.

Common reason to uncertain information is inadequate Performance Level (PL). PL means discrete level used to specify the ability of the safety-related parts of the control system to perform a safety function under foreseeable conditions. PL can be associated to probability of failed safety function [4]. Typically, integrators of the system try to choose equipment to the system so that they fulfill the PL requirements.

The origin of uncertain information related to indoor applications is often poor sensor perception due to e.g. high speed, object surface properties, misalignment of sensor (temporary or permanent), disturbance caused by other objects, object dimensions in specific height (e.g. forklift truck), lying person below detection field, inclined ground surface, a hole in the floor, object approaching behind a corner, or other object. Other origins for uncertain information coming outside of the machine are disturbed communication, old terrain map or wrong position information. Uncertain information can also be related to the situational awareness of a person. The person does not have correct information and makes a hazardous decision due to misinterpretation of the situation.

4 Conclusions

There is often some uncertain information related to situational awareness and some of it can be safety-critical. Usually, the rule is to keep the system safe by avoiding use of uncertain safety-critical information. However, in many cases additional uncertain information may improve safety. Such cases can be for example:

- Uncertain information from sensors with long detection range and low reliability can give important information before actual safety function is needed to avoid collision.
- Many AMRs have e.g. safety laser scanners to ensure basic safety cases at specific height, but additional sensors despite low PL may be needed to detect objects, with unusual dimensions and height.
- Devices, which have too low PL cause uncertainty, but additional redundancy may still be useful. This approach may be needed if there is no commercial equipment for the specific environment or situation that can fulfill PL requirements. For example, detection range may be too short, or calculating capacity inadequate for e.g. image processing. Difficult environmental conditions are more common in outdoor applications but in some cases e.g. temperature, moisture, vibration,

or lighting may cause limitations to indoors applications.

- Disturbances related to e.g. communication, lighting, and electro-magnetic radiation may cause uncertain information and the solution to improve situation is often case-dependent.
- Uncertain information can be related also to a broken machine and to question is it safe to drive it. For example, if the machine is at a place, where it can cause danger, it must be removed on specific conditions, like applying reduced speed.
- Malfunction of traffic control or warning system reduce situational awareness of persons. E.g., failed traffic light increase risk since persons may receive wrong information. The situation is better when the persons know that the information is uncertain (unknown certain vs. certain unknown).

As seen, there are many causes for uncertain information. Risk assessment is a suitable tool to estimate if the uncertain information is acceptable [5]. In some cases, the uncertain information may exist for a specific time, in a specific operation mode, load or in specific situation. One option to deal with uncertain information is to dynamically adjust speed, direction and separation distance to hazardous location according to the received sensor information. However, complexity increase uncertainty since the probability of errors is higher. Anyway, adequate level of safety can be achieved by increasing redundancy and accepting uncertain information in a controlled manner.

This paper is made in MixedFleet project, and it is mainly funded by Business Finland.

5 References

- [1] (EU) Machinery Regulation (EU) 2023/1230 of 14 June 2023. [Link](#)
- [2] Mica Endsley. 2000., Theoretical underpinnings of situation awareness. In Situation awareness analysis and measurement. Ed. Endsley M. and Garland D. ([Link](#)).
- [3] Hakanen T., Berger J., Karadeniz S. Liski T., Bunjaku A. Industrial mixed fleets: An empirical study on central situational awareness activities. ([Link](#))
- [4] ISO 13849-1. 2023. Safety of machinery Safety-related parts of control systems Part 1: General principles for design. ISO 164 p.
- [5] Malm T., Montonen J., and Hakanen T. 2022. Safety considerations for multi-purpose robots in industrial environments. VTT White Paper. 8 p. [Link](#)

Mechanistic AI: Enhancing Accuracy and Interpretability of Soft Sensors in Advanced Process Control

Bor, Alexander

Scientia Industrial Technologies Oy
alexander.bor@scientia.tech

Zakharov, Alexey

Scientia Industrial Technologies Oy
alexey.zakharov@scientia.tech

December 22, 2024

In modern refinery operations, precise and timely control of product quality is essential for optimizing performance and meeting stringent specifications. The Crude Distillation/Vacuum Distillation (CDU/VDU) traditionally relies on laboratory measurements for product quality assessment, with samples analyzed three or fewer times per day. This infrequent sampling is insufficient for closed-loop product quality control, which demands reliable readings at the control rate—typically once per minute. The absence of dependable on-line stream analyzers exacerbates the challenge, as existing analyzers often provide delayed responses unsuitable for multi-variable closed-loop control.

Soft sensors emerge as a vital solution to bridge this gap by establishing mathematical relationships between product quality and directly measured process variables. Common modeling techniques include regression analysis, artificial neural networks, and semi-empirical grey-box models. Serving as the "eyes" of an Advanced Process Control (APC) system, soft sensors enable real-time monitoring and control of product qualities without relying on delayed lab data or stream analyzers—these are utilized only for periodic calibration of the soft sensors.

Accurate soft sensors are crucial for the effective operation of APC systems, directly impacting the system's ability to maintain product quality within desired parameters. However, these methods have inherent deficiencies that can hinder their effectiveness. Traditional regression models often assume linear relationships between variables. Refinery processes are highly nonlinear and dynamic, involving complex interactions between multiple variables. Linear regression fails to capture these nonlinearities and interdependencies, leading to inaccurate predictions. Additionally, regression models are sensitive to collinearity among predictor variables, which is common in process data, potentially compromising the model's reliability. Although, such this shortcoming is addressable by partial least squares modeling technique, the underlying causality between variables will be obfuscated. Another widely used technique is artificial neural networks and while ANNs can model nonlinear relationships, they require extensive and representative datasets for training to generalize well. In the context of CDU/VDU units, the limited frequency of lab measurements means that available datasets are sparse and may not capture the full range of operating conditions. ANNs are also prone to overfitting, where the model learns the noise in the training data rather than the underlying process behavior, resulting in poor predictive performance on new data. Furthermore, ANNs are often considered "black boxes," lacking transparency and interpretability, which poses challenges for troubleshooting and gaining insights into process dynamics. Grey-box models are often offered as the compelling alternative to the aforementioned techniques. These models combine theoretical knowledge with empirical data, but they often rely on simplifications and assumptions that may not hold under all operating conditions. The accuracy of semi-empirical models can deteriorate when the process deviates from assumed conditions, such as changes in feedstock properties or equipment performance. They may also require significant effort to develop and maintain, including updating model parameters to reflect process changes, which can be resource-intensive.

Mechanistic AI offers a robust solution to these challenges by leveraging a general formulation of mass and energy conservation laws, rather than relying on detailed first-principle models. This design enables the prediction of measurable variables and the estimation of unmeasurable ones, all while maintaining reasonable model complexity. As a result, Mechanistic AI can close the loop from data collection to state and feed composition estimation—an

achievement typically unfeasible with detailed physics-driven models that are too complex for Kalman filter implementation. Additionally, the incorporation of fundamental physical principles helps regularize noise and reconcile inconsistencies in the data, allowing even low-quality datasets to be utilized effectively. Because of its underlying physics-based framework, Mechanistic AI models also generalize easily with minimal customization, ensuring they continue to produce valid results even with out-of-distribution data.

In contrast to traditional supervised machine learning models—which are usually non-transferable to other units, have unknown validity limits, are difficult to interpret, and cannot provide insights beyond the training data—Mechanistic AI offers unique features unattainable by other approaches. It combines data and physics in a novel way, producing reliable prediction and estimation results while providing deep insights into the system. Mechanistic AI is not only applicable in process control, requiring robust models, but also in predictive and prescriptive maintenance, necessitating a profound understanding of the system’s internal workings.

A significant advantage of Mechanistic AI over traditional machine learning models is its superior interpretability. Grounded in physical laws, Mechanistic AI models have structures and parameters that correspond to tangible physical phenomena, making them inherently understandable to engineers and operators. This transparency facilitates easier validation, troubleshooting, and acceptance by stakeholders who require insight into how predictions are made.

Automaatiopäivät 2025

Aihealue: Energiaan ja rakennusautomaation liittyvät ratkaisut

Rakennusten energiatehokkuus ja rakennusautomaatio

Sanni Siltala ja Tuomas Hietala, Sweco Finland Oy

Vuoden 2025 alusta rakennuksilta vaaditaan rakennusautomaatiojärjestelmää, asuinrakennuksia lukuun ottamatta. Vaatimus tulee laista varustaa rakennukset automaatio- ja ohjauksjärjestelmillä, joka panee täytäntöön energiatehokkuudesta annetut direktiivit 2012/27/EU ja 2010/31/EU.

Rakennusautomaation tulisi lain mukaan jatkuvasti seurata ja kirjata energian käyttöä, tehdä vertailevaa analyysiä rakennuksen energiatehokkuudesta ja havaita esim. tehohävikki ja hälyttää siitä, mahdollistaa viestintä erilaisten järjestelmien kesken ja seurata sisäympäristön laatua. Nämä eivät kuitenkaan kaikilta osiltaan toteudu.

Energiatehokkuus standardi SFS-EN ISO52120 määrittelee rakennusautomaatiojärjestelmälle luokitukset A-D. Rakennukset, joille vaaditaan lain mukaan rakennusautomaatiojärjestelmä vuoden 2025 alusta, menevät joko luokkaan A tai B. Tulevaisuudessa luokan D rakennuksia ovat vain pientalot.

Asuinkerrostalot jäävät laissa vaaditun rakennusautomaatiojärjestelmän ulkopuolelle, mutta rakennusten energiatehokkuus vaatimukset ajaisivat ne luokkaan B. Rakennusten energiatehokkuusdirektiivissä (EPBD) määritellään asuinrakennusten energiansäästö tavoitteet, jotka ajavat siihen, että myös rakennusautomaation avulla saadut säästöt tarvitaan osaksi tavoitetta.

Nykyinen E-luvun laskenta ei ota huomioon rakennusautomaation energiatehokkuusluokkaa. E-luvun rinnalle on tulossa SRI-arviointi, joka ottaa kantaa rakennusautomaation kyvykkyyksiin tehdä rakennuksesta älykäs.

Tilaajilla ja suunnittelijoilla on suuri merkitys rakennusten lain vaatimusten täyttämässä ja energiarvirtojen hallinnassa. Esim. ilman tilaajien valvotuneisuutta voi käydä niin, että asuinkerrostaloja yritetään toteuttaa luokan C-mukaisesti, eikä kaikkia säätö- ja mittaustoimintoja toteuteta säästöystistä. Tai toimistokiinteistöjen energiankulutus on suurta vastaaviin rakennuksiin verrattuna, eikä tätä olla huomattu, koska todellisia kulutustietoja ei ole verrattu tavoitearvioihin.

Mika Ruusunen*, Petri Hietaharju, Outi Ruusunen ja Aki Sorsa

Opetuksen ja oppimisen tehostaminen tekoälymalleilla

Tiivistelmä: Dokumentti käsittelee tekoälymallien hyödyntämistä Oulun yliopiston säätötekniikan opetuksessa. Esimerkeissä tekoälyä on käytetty avatarvideoluentojen tekemiseen, opiskelijoiden tehtävien arviointiin ja opinnäytetöiden aiheiden suunnitteluun. Tekoälymallien hyödyntämisellä on siten tehostettu opetusresurssien käyttöä ja monipuolistettu opetuksen työkaluja.

Avainsanat: generatiivinen tekoäly, opetussisällön suunnittelu, opetusresurssit

*Vastaava kirjoittaja: Oulun yliopisto, E-mail: mika.ruusunen@oulu.fi

Muut kirjoittajat: Oulun yliopisto, E-mail: petri.hietaharju@oulu.fi, outi.ruusunen@oulu.fi, aki.sorsa@oulu.fi

1 Johdanto

Yliopisto-opetuksessa etäopetus ja erilaiset opetusta visualisoivat tallenteet ja videot ovat tulleet arkipäiväisiksi, mikä on tarjonnut opetushenkilökunnalle uusia työkaluja ja tapoja tuottaa ja jakaa opetuksen materiaaleja. Zoom- ja Teams-sovellusten avulla järjestetyt etäluennot ja niistä tehdyt luentotallenteet ovat yleisesti käytössä lähiopetuksen rinnalla. Pelkkien luentotallenteiden jakaminen ei kuitenkaan ole aina tehokkainta oppimisen näkökulmasta. Tehokkaampia olisivat lyhyet, tiivistetyt opetusvideot, joiden sisältö on tarkoin suunniteltu [1]. Opetushenkilökunnan rajalliset aikaresurssit kuitenkin usein estävät laajamittaisen videoluentojen ja opetusvideoiden tuottamisen.

Tekoälymallien yleistyminen on tuonut ne mukaan yliopisto-opiskeluun ja -opetukseen. Opiskelijat ja tutkijat käyttävät niitä jo sujuvasti vähintään tiedonhaun työkaluna. Tekoälyn hyödyntämisen vaikutuksia oppimiskokemukseen ja akateemiseen suoriutumiseen avoimessa sekä etäopetuksessa on dokumentoitu laajasti esimerkiksi vuonna 2024 julkaistussa artikkelissa [2]. Opetuksessa tekoälymalleja voidaan hyödyntää esimerkiksi tiedonhaun ja -tiivistämisen lisäksi sisällön tuottamisessa, tiedon visualisoinnissa sekä luentojen ja materiaalien

kääntämisessä eri kielille [3]. Syväoppimismallien merkitystä puheen muuntamisesta tekstiksi ja eri kielille on käsitelty esimerkiksi julkaisussa [4]. Tekoälymallien hyödyntämistä opetusvideoiden tuottamisessa taas on esimerkiksi artikkelissa [5].

2 Tavoite

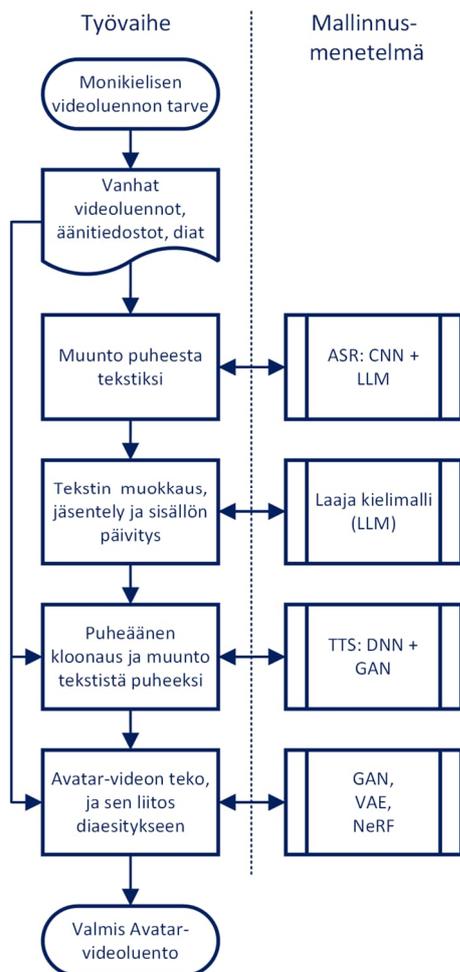
Tavoitteena on esittää esimerkeillä tekoälymallien hyödyntämistä yliopisto-opetuksessa. Tarkoituksena on tehostaa opetusresurssien käyttöä ja oppimista tekoälymallien avulla, osana lähiopetusta. Keskiössä on opiskelijoiden oppiminen ja monipuolisten ohjelmistotyökalujen käyttö opetuksessa.

3 Materiaalit ja menetelmät

Opetuksen ja oppimisen tehostamiseksi esitellään kolme esimerkkitapausta, joissa on hyödynnetty tehokkaasti erityyppisiä tekoälymalleja: Avatarvideoluennon tuottaminen vanhoista opiskelumateriaaleista, opinnäytetöiden aiheiden suunnittelu sekä essee-tyyppisten tehtävien tarkistamisen nopeuttaminen jatkuvan arvioinnin sujuvoittamiseksi.

Avatarvideoluennon tuottamisen eri työvaiheet ja niissä käytetyt tekoälymallit on esitetty kuvassa 1. Tässä yhteydessä avatar on digitalisoitu luennoitsijaa vastaava hahmo. Esimerkissä on hyödynnetty aiempina vuosina tallennettuja englanninkielisiä videoluentoja ja niihin liittyviä luentomateriaaleja. Tallenteiden ääniraidat muunnettiin ensin automaattisesti tekstiksi (ASR, Automatic Speech Recognition) TurboScribe-sovelluksella [6], jossa hyödynnetään esiovetun konvoluutioneuroverkon (CNN) ja laajan kielimallin (LLM) yhdistelmää. Tuotetun puhetekstin muokkaus ja jäsentely koostui sisällön päivittämisestä sekä kielenhuollosta laajaa kielimallisovellusta GPT-4o hyödyntäen [7]. Avattaren ääneksi valittiin tässä tapauksessa luennon pitäjän oma puheääni, jonka kloonaukseen ja muokatun tekstin puhumiseen (TTS, Text to Speech) käytettiin esiovetettua syvän neuroverkon (DNN, Deep Neural Network) ja generatiivisen kilpailevan verkon (GAN, Generative Adversarial Network) yhdistelmää HeyGen-sovelluksessa [8]. Viimeisenä vaiheena tehtiin luennoitsijan digitaalinen avatar hyödyntäen GAN-

mallirakennetta, variaatioautoenkooderia (VAE) ja mahdollisesti neuraalista säteilykenttä-mallia (NeRF) HeyGen-sovelluksella. PowerPoint-muodossa ollut luentoaineisto yhdistettiin sen jälkeen puhuvan avattaren kanssa videoluennoksi. Valmis videoluento voidaan muuntaa tällä tavoin tehtynä nopeasti mille tahansa kyseisen sovelluksen kielimallille esiopetettulle kielelle. Lisäksi videon automaattinen tekstitys on mahdollista samalla sovelluksella, joka hyödyntää suoraan avattaren puhumaa, luennoitsijan itse alun perin englanniksi tuottamaa tekstisisältöä.



Kuva 1. Avatar-videoluennon tuottaminen vanhojen opetusmateriaalien pohjalta ja käytetyt tekoälymallit.

Opinnäytetöiden aiheiden ja sisällön suunnittelussa taas hyödynnetään tyypillisesti laajoja kielimalleja (Gemini, DeepSeek, ChatGPT, QWEN, ja Copilot) yhdessä opiskelijoiden kanssa. Niitä käytetään tässä yhteydessä tuottamaan iteroimalla tiiviitä yhteenvetoja potentiaalisista opinnäytetöiden aiheista.

Jatkuvan arvioinnin toteuttaminen esseetyyppisten kotitehtävien avulla työllistää opetushenkilökuntaa varsinkin silloin, kun opiskelijoita on kurssilla paljon.

Vastausten lukemista ja olennaisten asioiden löytämistä on mahdollista tehostaa esimerkiksi ChatGPT:n ja Copilotin avulla. Molemmat tekoälymallit suoriutuvat hyvin vastausdokumentin sisällön tiivistämisestä. Tiivistelmän tekeminen ei ota kantaa vastauksen oikeellisuuteen ja tehtävän arviointi jää ihmisen tehtäväksi, mutta luettavan tekstin määrä pienenee huomattavasti.

4 Tulokset ja johtopäätökset

Käyttökokemusten perusteella opinnäytetöiden aihealueiden ja sisällön hahmottaminen laajoja tekoälymalleja hyödyntämällä nopeuttaa töiden aloittamista ja madaltaa opiskelijan aloituskynnystä. Tekoälymalleilla voidaan esimerkkien perusteella tuottaa myös tehokkaasti opetussisältöä, kunhan se määritellään tarkasti. Vastuu sisällön oikeellisuudesta ja arvioinnin oikeudenmukaisuudesta on kuitenkin aina ihmisellä. Tekoälysovellukset voivat monipuolistaa siten opetuksen työkaluja ja mahdollistavat resurssien vapauttamista oppimiskokemuksen kehittämiseen.

5 Lähdeluettelo

- [1] Auvinen, H. (2022) Opetusvideoiden hyödyntäminen itseopiskelumateriaalina verkkokurssilla, Pro-gradu tutkielma. Helsingin yliopisto.
- [2] Adewale, M. D., Azeta, A., Abayomi-Alli, A., & Sambo-Magaji, A. (2024). Impact of artificial intelligence adoption on students' academic performance in open and distance learning: A systematic literature review. *Heliyon*, 10(22), e40025. <https://doi.org/10.1016/j.heliyon.2024.e40025>
- [3] Salih, S., Husain, O., Hamdan, M., Abdelsalam, S., Elshafie, H., & Motwakel, A. (2025). Transforming education with AI: A systematic review of ChatGPT's role in learning, academic practices, and institutional adoption. *Results in Engineering*, 25, 103837. <https://doi.org/10.1016/j.rineng.2024.103837>
- [4] Ahlawat, H., Aggarwal, N., & Gupta, D. (2025). Automatic Speech Recognition: A survey of deep learning techniques and approaches. *International Journal of Cognitive Computing in Engineering*, 6, 201–237. <https://doi.org/10.1016/j.ijcce.2024.12.007>
- [5] Netland, T., Von Dzengelevski, O., Tesch, K., & Kwasnitschka, D. (2025). Comparing human-made and AI-generated teaching videos: An experimental study on learning effects. *Computers & Education*, 224, 105164. <https://doi.org/10.1016/j.compedu.2024.105164>
- [6] <https://www.turboscribe.ai/> [Viitattu 7.3.2025].
- [7] <https://chatgpt.com/> [Viitattu 7.3.2025].
- [8] <https://www.heygen.com/> [Viitattu 7.3.2025].

Tero Hietanen OAMK*, Outi Rask TAMK, Veli-Pekka Pyrhönen TAU, Jari Böling TY ja Ville Kyrki Aalto

Automaatiokoulutuksen tulevaisuus 2024

Abstract: Laatuun toinen automaatiokoulutuksen tulevaisuus tilaisuus järjestettiin automaatioseuran uudistuneissa tiloissa syksyllä 2024. Tilaisuus noudatti hyväksi havaittua konseptia; jossa teollisuus, koulutus ja opiskelijat tuotiin alustusten jälkeen pohtimaan yhdessä koulutuksen kehittämistä työpajoissa.

Tilaisuuden tuloksia tullaan levittämään ja käsittelemään useammassa julkaisuissa. Tässä artikkelissa luodaan automaatiokoulutuksen kokonaistilasta arvio ja toimenpide-ehdotus.

Keywords: Koulutus, tietoturva, tekoäly

***Corresponding Author:**

E-mail: * Tero.Hietanen@oamk.fi

Second Author: Outi.Rask@tuni.fi, veli-pekka.pyrhonen@tuni.fi, jari.boling@utu.fi ja ville.kyrki@aalto.fi

1 Johdanto

Suomen automaatioseuran koulutustoimikunta on yksi vanhimmista automaatioseuran työryhmistä. Olemme työskennelleet automaatiokoulutuksen verkostojina ja puolestapuhujina jo pitkään. Toimintaan kuuluu mm. erilaisten tapahtumien järjestäminen ja julkaisujen tuottaminen. Automaatiokoulutuksesta kiinnostuneet ovat tervetulleita osallistumaan toimikunnan työskentelyyn.

Automaatiokoulutuksen tulevaisuus 2024- tilaisuus järjestettiin automaatioseuran uudistetuissa tiloissa Pasilassa 17.9.2024. Tilaisuus oli toinen laatuun ja edellinen pidettiin reilu kymmenen vuotta sitten. Tilaisuudessa tarkasteltiin automaatiokoulutuksen historiaa, nykytilaa ja tulevaisuutta ammattikorkeakoulujen, yliopistojen sekä teollisuuden näkökulmista.

Automaatiokoulutuksessa on nojaututtu laadukkaaseen tieteelliseen ja soveltavaan tutkimukseen. Alan insinööreillä ja tohtoreilla on hyvät

näkökulmat teollisuudessa. Automaatio-osaamiseen pohjautuvia korkean teknologian startupeja on myyty kansainvälisille sijoittajille viime päivisiin asti tästä esimerkkinä Silo AI.

Viime aikoina automaatiotekniikan koulutusta on lisätty esim. Turun yliopistossa. Toisaalta uusia tutkinto-ohjelmia on perustettu esim. teollisen internetin, automaation tietoturvan ja tekoälyn koulutukseen.

Tässä artikkelissa luodaan automaatiokoulutuksen kokonaistilan arvio hyödyntäen vuoden 2014 ja 2024 tilaisuuksien esityksiä sekä ryhmätöitä. Tilannekuvan pohjalta luodaan näkökulmia opiskelijoiden, oppilaitosten, yritysten sekä yhteiskunnan suuntaan.

2 Automaatiokoulutuksen tulevaisuus 2014

Teollisen tuotannon arvon romahdettua 2008–2009 Suomen julkinen talous painui rakenteellisesti alijäämäiseksi. Julkista taloutta alettiin korjata mm. jäädyttämällä koulutuksen rahoitusta sekä koulutusorganisaatioiden rakenteita muuttamalla. 2014 tutkimuksen rahoitus oli myös muuttumassa voimakkaasti. Valtiollisesta rahoituksesta oltiin siirtymässä kohti EU:n rahoituskanavia. Kaikella tällä oli suuri vaikutus automaatiotekniikan koulutuksen kannalta.

Ammattikorkeakouluissa automaatiotekniikan opetus integroitui sähkötekniikan kanssa sekä hajaantui talo-, tieto- ja konetekniikkaan. Yliopistoissa automaatiotekniikan opetusta annettiin tyypillisesti osana tieto-/informaatiotekniikka tai konetekniikkaa.

2014 pidetyn tilaisuuden puheenvuoroissa automaatioseuran puheenjohtaja Harri Happonen esitti koulutuspoliittisen kysymyksen: ”Tarvitseeko Suomi seuraajia vai edelläkävijöitä?”. Marjo Uusi-Pantti Teknologiateollisuus ry:stä korosti palveluliiketoiminnan ja korkean teknologian tuotteiden olevan Suomelle mahdollisuus menestyä

kansainvälisessä kilpailussa. Heimo Heikkilä Neste Jacobsilta odotti prosessiautomaation koulutuksen tuovan osaamista automaatiojärjestelmiin, instrumentointiin sekä säätötekniikkaan. Laajemmin odotettiin osaamista automaation tietoturvaan sekä kansallisen huoltovarmuuden turvaamiseen.

Seminaarin ryhmätöissä tarkasteltiin automaatiotekniikan tutkimusta, koulutuksen sisältöä, rahoitusta, työelämälähtöisyyttä sekä teollisuuden odotuksia koulutukselle. Tulevaisuuden tarpeina nähtiin edellä mainittujen lisäksi mm. tieto- ja informaatiotekniikan osaaminen, yleiset työelämätaidot sekä erityisesti projektiosaaminen. /1/

3 Automaatiokoulutuksen tulevaisuus 2024

Tilaisuuden avasi automaatioseuran puheenjohtaja Veikko Ruuhonen toivottaen paikallaolijat ja etäosallistujat tervetulleeksi. Automaatioseuran koulutustoimikunnan puheenjohtaja Tero Hietanen alusti tilaisuuden sekä kertoi vuoden 2014 tilaisuuden keskeiset tulokset. Puheenvuorossaan hän nosti nykytilanteen haasteiksi koulutuksen perustan murenemisen, koulutusrahan kohdentumisen, opiskelijan työviikon, etäopiskelun, automaatiokoulutuksen laaja-alaisuuden sekä työelämän muutosnopeuden.

Leena Pöntynen teknologiateollisuus ry:stä tarkasteli puheenvuorossaan teollisuuden odotuksia vastavalmistuville, sekä pohti miten uusien teknologioiden muutokset vaikuttavat työhön ja odotuksiin koulutukselle. Taustalla on huoli kelpoisen työvoiman saannista teollisuuteen.

Jarno Varteva Metropolia ammattikorkeakoulusta otti kantaa ammattikorkeakoulujen koulutushaasteisiin otsikolla: ”Insinööriopiskelijakoulutuksen kriisi pahenee!”. Vartevan tarkkanäköisistä havainnoista on hyvä poimia makrotason koulutushaaste, jossa hän tarkasteli koulutusrahan kohdentumista opetukseen. Ja totesi, että vain noin kolmasosa koulutuksen rahoituksesta käytetään opettajien palkkoihin. Valtaosa kuluu vuokriin, hallintoon ja palveluihin.

Tilaisuutta varten järjestettiin opiskelijakysely Tampereen yliopistolla. Opiskelijoilta kysyttiin odotuksia automaatiotekniikan opiskelusta. Kyselyn tuloksia esitteli automaatiotekniikan opiskelija Niilo Lamminen. Opiskelijat kokivat, että automaatioopinnoille hyvän pohjan luovat matemaattisluonnontieteelliset opinnot sekä kyvykkyyden loogiseen ajatteluun. Yliopisto-opiskelijat

kokivat, että systeemiteoria sekä ohjelmointi ovat keskeisiä kompetensseja automaatioalalla. Yleisinä kompetensseina nähtiin projektiosaaminen, yhteistyötaidot sekä dokumentointi.

Veli-Pekka Pyrhönen Tampereen yliopistolta oli seurannut 8 vuoden ajalta opiskelijoille teetetyn matemaattisluonnontieteellisen alkutestin tuloksia. Testin keskeisenä tuloksena oli matemaattisluonnontieteellisen osaamisen merkittävä heikkeneminen pitkällä aikavälillä.

Tapahtuman työpajoissa pohdittiin 4 teeman avulla vaihtuvissa pienryhmissä alan koulutuksen tulevaisuutta, kysymyksinä olivat:

1. Automaatiokoulutuksen osaamisperusta tulevaisuudessa?
2. Automaation kompetenssit tulevaisuudessa?
3. Työelämän odottamat yleiset kompetenssit tulevaisuudessa?
4. Työelämän odotukset vastavalmistuneelle tulevaisuudessa?

Työpajoista voidaan tiivistää kysymyksittäin tuloksina, että, 1. Automaatiotekniikan osaamisperusta nojautuu edelleen matemaattisluonnontieteelliseen osaamiseen ja systeemijatteluun. Looginen ajattelu, ohjelmointitaidot, algoritmiosaaminen, data-analyysi ja laaja-alainen informaatiotekniikan hallinta. 2. Tekoäly, digitaaliset ratkaisut, tietoturva (NIS2), automaatiostandardit, monimutkaisten järjestelmien hallinta, kriittisen tiedon hallinta sekä monen toimittajan ympäristöjen ja projektin hallinta. 3. Kansainvälisyysosaaminen, projektiosaaminen, työelämätaidot, jatkuva oppiminen, turvallisuus ja standardit sekä johtamistaidot. 4. Suunnitteluosaaminen, toimialan perustuntemus, käyttöönotto tehtävät, nousevien teknologioiden hallinta, rohkeus kysyä ja uudistaa sekä valmius siirtyä uusiin tehtäviin.

Kysymyksillä oli selkeää päällekkäisyyttä ja niiden esittäminen kysymyksittäin vaati lisäanalyysiä. Esitämme yksityiskohtaisemmat tulokset automaatiopäivillä.

4 Pohdinta ja johtopäätökset

Suomessa on lähivuosina eläköitymässä suuri joukko vaativissa asiantuntijatehtävissä ja johtotehtävissä työskenteleviä. Tämän paikkaamiseen tulisi löytää

työvoimaa suppenevista ikäluokista sekä esim. maahanmuuton kautta. Yliopisto ja korkeakoulutuksen koulutusodotukset ja lupaukset ovat valtakunnallisesti irronneet todellisuudesta. Koulutettaviksi kelpaavat kaikki ja karsintaa suoritetaan hyvin vähän valtaosissa oppilaitoksia. Tämän vastapainona oppilaitoksille annetaan lisää tehtäviä sekä toisaalta koulutuksen rahoitus kuluu vuokriin ja hallintoon.

Tämä johtaa tilanteeseen, jossa opiskelijan ohjattu toiminta koulussa ei muodosta enää työviikkoa, vaan on pikemminkin harrastus. Jo aiempien koulutuspoliittisten päätösten vaikutukset näkyvät korkea-asteelle tulevien opiskelijoiden osaamisen heikkenemisenä ja vaihtelevina osaamisvajeina.

Automaatio on alana kehittyvä ja kasvava. Lisäksi osaajapula yrityksissä on suuri. Haasteena on osaavan työvoiman kouluttaminen. Tämän toteuttaminen edellyttää:

1. Koulutuksen resurssien keskittäminen ydintoimintaan eli opetukseen ja ohjaukseen.
2. Opiskelijalle pitää tarjota työviikko eli opiskelu ei voi olla harrastus!
3. Henkilökohtaiset suoritukset ja suoritusten suunnittelu koko opiskelun ajalle.
4. Työelämän tukiprosessit kuntoon, mahdollisuudet opiskelijoille sekä koulutuksen yhteiskehittäminen.
5. Oppilaitosten erikoistuminen siten, että vastataan valtakunnalliseen osaajapulaan alueellisen tarpeen lisäksi.

5 Kirjallisuus

1. Rask Outi, Zenger Kai, Hietanen Tero, Inkinen Markku., Automaatiokoulutus Suomessa, Automaatiöväylä 5/2014, Suomen Automaatioseura ry, 2014

Teemu Kumpulainen

Varjoista valoon: Järjestelmien kartoitus ja matka hallintaan

Abstract:

Kyberturvan ensimmäinen kenttätehtävä alkaa laitteistojen ja järjestelmien kartoituksesta. Ilman tiukkaa vaatimusta toimituksissa, ajansaotossa laitoksiin on kertynyt eri valmistajien komponentteja, ohjelmistoja sekä eri tasoisia järjestelmän sisäisiä verkkoja. IT näkökulmasta kaikkea tätä voisi kutsua "Shadow IT" eli varjo IT nimellä.

Kysymys kuuluukin kuinka voin suojata jo kytkettyjä järjestelmiä eri uhilta ja kuinka uskallan kytkeä vanhoja järjestelmiä IT:en?

Pelkotilat ja kysymykset vähenevät, kun laitteistot saadaan kartoitettua, riskit, uhat ja vastatoimet määriteltä sekä vastuuhenkilöt nimettyä.

Laitekannan sekä järjestelmien kartoitukseen ei ole yhtä valmista ratkaisua vaan työkalut, tapa, henkilöstö sekä tarvittavat tiedot tulee määritellä kokonaisuutena.

Laitteistojen skannaaminen

Aktiivinen, passiivinen vai manuaalinen keräys?
Kuka kerää ja saadaanko laitteista kerättyä kaikki tarvittavat tiedot?
Miten saadaan ylläpidettyä motivaatiota puuduttavaan tiedonkeruuvaiheeseen?
Jokaisessa tavassa on hyvät puolet ja puutteet.
Laitetietojen lisäksi täytyy pystyä keräämään ohjelmistotiedot Windows ja linux pohjaisista käyttäjärjestelmistä.

Aktiivisella skannauksella saadaan irti laitetiedot. Jotta aktiivisella skannauksella saadaan irti tarpeeksi laadukasta dataa, on kohdelaitteen tuettava tietoa antavia protokollia ja lisäksi niihin pitää olla verkon kautta pääsy.

Passiivisella monitoroinnilla nähdään, kuinka laite on ohjelmoitu kommunikoimaan ja ketkä ovat sen kommunikointipartnerit. Passiivinen tiedonkeruu vaatii tietenkin laitteen, jonka läpi tieto kulkee. Lisäksi tiedon olisi hyvä olla salaamatonta, jotta pakettien sisällöstä

saadaan irti lisätietoja.

Manuaalisella kartoituksella saadaan kerättyä operointipohjaista, kirjoittamatonta tietoa, mikä on erittäin hyödyllistä jatkovaiheissa. Laitosta ja kabinetteja kierrettäessä tulee tarkkailtua myös fyysistä suojausta sekä hallitsemattomia ja virrattomia laitteita. Tähän työhön vaaditaan monesti mukaan kunnossapito- tai automaatiohenkilö, kenellä on valtuudet avata sähkökaappeja ja liikkua tuotannossa.

Laitteistotietojen keruu semi-automaattisesti ja manuaalisesti voi olla tekijälle tai tekijöille puuduttavaa. Tehtävän "epäseksikkyyttä" voi piristää perustamalla yhteisö, tarinallistamisella ja pelillistämällä. Näistä muutama esimerkki.

Laitteistotietojen jatkokäsittely

Jatkokäsittelyvaiheina on datan yhdistäminen eri tietolähteistä. Eri lähteistä luettuna samasta laitteesta voi syntyä duplikaatteja, sekä eri ohjelmistojen keräämät nimikkeet saattavat erota toisistaan, jolloin niitä pitää manuaalisesti yhdistellä ja muokata.

Kun tiedot on saatu järjesteltyä, tulee päätettäväksi, missä tiedot säilytetään (CMDDB) ja tukeeko se tarvittavia tietomalleja. Tarvittaessa tiedot voi koota väliaikaisesti, vaikka exceliin.

Ryhmittelyn jälkeen voidaan aloittaa järjestelmien ja laitteistojen erottelut ja paloittelusuunnitelmat verkkopohjaista segmentointia varten. Segmentointityöpajoissa korostuu ja huomataan kerätyn datan riittävyys ja laatu, sekä vastuussa olevien henkilöiden operointi ja järjestelmä tuntemus.

Keywords: OT cybersecurity, Asset discovery and inventory, Champions, Data correlation, Segmentation

***Corresponding Author: Corresponding Author:**
E-mail: teemu.kumpulainen@konecranes.com

1 Introduction

Puhevuorossa käydään läpi tietojenkeruu ja sen muutama jatkovaihe. Esityksen läpivientinä käytetään

esimerkkinä omakohtaisia kokemuksia vaiheiden läpiviennistä.

2 Extended abstracts

3 Bibliography

Kumpulainen Teemu

16 kokemus komponenttivalmistajan ja OT palvelun tarjoajan puolelta sisältäen vianhakua, suunnittelua sekä palveluiden rakentamista tuotantoympäristöihin.

Nykyään päivätöissä Konecranesin Globalissa organisaatiossa OT tietoturvan erikoisasantuntijana.

Ohjaavina sanoina työelämässä toimivat, "yksinkertainen on kaunista ja toimivaa" sekä "ihmislähtöinen kyberturva".

Authors may use any established style for formatting the references and for citing references in the text. The style should be consistent throughout the paper. The list of references should only contain papers cited in the text.

Yrjö Majanne*, Venla Vilhonen, Sami Repo, Matti Vilkkko

Green Transition, Systemic Approach to Green Hydrogen Based Power2X Value Chain

Abstract: Green hydrogen based Power2X value chain consists of renewable electricity production, electrolysis-based hydrogen production, end product production such as methane, methanol and ammonia, and final use of these end products combined with energy transmission and storing in different forms. Different stages of the value chain have different operational and regulative requirements, which must be brought together to make the whole system operable. This paper presents some results how operational characteristics and physical locations of value chain units effect on the operation and costs of the whole energy system. Analysis is based on simulation and scenario work carried out in Business Finland financed HYGCEL project.

Keywords: Green transition, Hydrogen, Energy systems, System dynamics

*Corresponding Author: Yrjö Majanne: Tampere University, E-mail: yrjo.majanne@tuni.fi
Venla Vilhonen: Polar Night Energy, E-mail: venla.vilhonen@pne.fi
Sami Repo: Tampere University, E-mail: sami.repo@tuni.fi
Matti Vilkkko: Tampere University, E-mail: matti.vilkkko@tuni.fi

1 Extended Abstract

Transition from fossil carbon to carbon free/neutral energy system is an enormous project. In 2023 the global energy consumption was 182 230 TWh, of which 140 000 TWh, 76 %, was fossil origin. In Finland the total primary energy consumption was 366 TWh, of which 110TWh, 30%, was fossil origin. Thus, getting rid of fossil energy is not a fine tuning of the existing energy system, but it means a revolution in the whole society, how energy will be produced and consumed.

Electrification of energy consumption as much as possible by renewable and low carbon electricity will be in a key role in the energy transition. Where direct electrification is not feasible, hydrogen and its' derivatives will be utilized.

One main challenge in green transition is the variable nature of renewable electricity production. Main sources of new installed renewable electricity will be wind and solar power. Because of the giant scale of the new electricity production capacity required to replace fossil energy, the share of variable renewable energy will dominate the electric power systems in future.

As well known, power production and consumption in electric power system must be equal in every second. In order to help to keep the electric power system stable, EU has imposed a delegated act of the Renewable Energy Directive (RED) which states that in green hydrogen production, the renewable electricity consumption of electrolyzers must follow the contracted electricity production in one hour time window. This will enter into force from 2030. Before that the balancing time window is one month.

This requirement implies that green hydrogen production will be variable as well as renewable electricity production. This will have several impacts on the whole Power2X value chain. Electrolyzers must be operated at frequently varying operation points, which must be taken into account in process and automation design. Also the dimensioning of the electrolyzer capacity must be optimized based on the generation profile of the contracted electricity producer and desired total production capacity. The full load hours of the designed electrolyzer plant will be around 4 000 hours, which means poor investment efficiency. However, with estimated investment costs of electricity battery storages and electrolyzers, it is more economic to invest in over capacity of electrolyzers instead of required battery capacity to smooth the fluctuations in electricity production.

Hydrogen production and production of synthetic methane or methanol has sectoral interconnections which must be considered. In hydrogen production app. 30 % of supplied electric energy is converted to heat, which can be applied in heating applications, e.g. in district heating. This will improve the operation economy of the hydrogen production but must be included in the operation design of the process. In hydrogen methanation, CO₂ is needed as another raw material besides hydrogen. CO₂ will be captured from

flue gases of combustion plants like industrial or heating CHP plants. Carbon capture process is energy intensive and has an impact on the thermal power output of the CHP plant. This must also be considered in system design and operation.

Hydrogen end use and refining processes are not flexible but must be operated at constant operation points or within a narrow operation range with slow change rate of the operation point. They cannot be frequently switched on and off. This results that Power2X value chain must contain also hydrogen buffer storages to smooth the variable hydrogen production to constant supply flow for further processes. It is also an optimization task to design the optimal storage capacity according to the investment cost of storage capacity and value of increased production achieved by a certain storage capacity.

Renewable electricity production sites are distributed over large regions. This leads to a need of energy transmission. If hydrogen is produced near electricity production, the transferred media will be hydrogen. If hydrogen is produced near industrial end use, huge amount of electricity must be transferred across the country. Which is feasible depends on the geographical locations of the renewable energy production sites in relation with the main power transmission grid and required capacities. In case of huge power transmission needs, hydrogen grid is superior. One 1,2 m diameter hydrogen pipe at 80 bar pressure can transmit 12 GW power, which is as much power as 15 parallel 400 kV electricity lines.

As described, Power2X value chain has many interconnected characteristics and sectoral connections, which must be considered when designing the structure and the operation of the total system. The role of automation will be essential when synchronizing and optimizing the operation of the whole value chain. In the proposed paper we will introduce some results about different scenarios modelled and simulated about the future Finnish energy system. The scenarios will analyze the behavior of different capacities and locations of renewable electricity, hydrogen, and end product productions and resulting needs of energy transportation and storing.

The presented research work is done mainly in Business Finland financed HYGCEL research project in 2022 - 2024.

Antti Jaatinen

Kokemuksia langattomien teknologioiden käytöstä automaatiassa

Tiivistelmä: Langattomien teknologioiden kehitys on ollut iso trendi ja tullut automaatioonkin. Tässä artikkelissa kerron kokemuksia erilaisten teknologioiden käytöstä kahdesta eri näkökulmasta; ovatko ne automaation kannalta riittävän ”kypsiä” ja mitä niissä on otettava huomioon globaalissa käytössä.

Teknologiat:

Lyhyt kantama eli IEEE 802.14.5 ja Bluetooth

Keskipitkä matka eli WLAN 802.11x

WAN eli mobiilidata 4G ja 5G

Avainsanat: IoT, langattomat teknologiat

Antti Jaatinen: Valmet Automation,
antti.jaatinen@valmet.com

Second Author: Affil, E-mail: email@email.edu

(artikkelin julkaisuversioon on tarkoitus lisätä kaavioita ja esimerkkejä ja se voi myös olla englanniksi tarpeen mukaan. Artikkelin on tarkoitus lähinnä toimia 15 min esitelmänä ja voi tarvittaessa olla kaksikin eri esitelmää)

1 Johdanto

Langattomien teknologioiden kehitys on ollut viime vuosikymmenten hieno saavutus. Käytämme niitä päivittäin ja luotamme niiden toimivuuteen. Kuitenkin teollisessa automaatioympäristössä ne tuntuvat olevan haasteellisia. Tässä artikkelissa esitän kokemuksia langattomien tekniikoiden soveltamisesta mittaukseen ja automaatioon.

2 Langattomuuden valinta

Langattoman tekniikan tulisi aina olla tietoisesti valittu eikä oletusarvo. Yleensä perusteena mainitaan vapaus anturin sijoitukselle ja säästö kaapeloinnissa ja I/O:ssa. Tällöin tarkoitetaan usein anturin akku- tai

patterikäyttöisyyttä, eli anturi on kokonaan ”langaton”, eikä vain siirrä tietoa radioteitse.

Rajallinen sähkönsyöttö tarkoittaa väistämättä perusteellisia rajoituksia laitteen toiminnalle. Suunnittelussa pitäisi heti tunnistaa, millaisesta käyttötapauksesta on kyse.

Toisaalta, vaikka sähköä olisi saatavilla, teknologioissa on valtavia eroja sekä standardeissa että etenkin käytännön toteutuksissa.

3 Lyhyt kantama (PAN)

Teollisessa ympäristössä termi Personal Area Network ei liene se kaikkein kuvaavin. Tässä kuitenkin tarkoitan IEEE 802.14.5 perheen teknologioita, joista tunnetuimmat kenties Zigbee ja 6LoWPAN. Tällaisten päälle on rakennettu myös mesh-verkkoja, kuten Threads.

4 Keskipitkä matka eli WLAN

Langaton lähiverkko eli WLAN eli WiFi ja virallisesti IEEE 802.11 perhe on teknologiana kehittynyt valtavasti esittelystä lähtien. Kodeissa ja toimistoissa ei välttämättä ole muuta tietoverkkoteknologiaakaan kuin WLAN. Mutta mitä haasteita teollisessa ympäristössä tulee vastaan?

- Käytössä ovat lupavapaat radiokaistat, joilla voi olla paljonkin liikennettä.
- Radiotilaa ei hallitse ainakaan laitetoimittaja. Samoille taajuuksille tulee varmasti lisää jakajia käyttöönoton jälkeen.
- Kentälaitteissa voi olla yllättävän vanhoja standardeja käytössä, jotka haittaavat kaikkien verkkojen toimintaa.
- Standardit lupaavat kaikenlaista hyvää, mutta reunaehdot ei paljasteta, tai kaikkea ei ole edes implementoitu tuotteisiin.
- Tukiasema voi olla hyvinkin edistynyt, mutta kentälaitteissa toteutukset varmasti yksinkertaisempia, etenkin antennit.

- Globaalisti käytössä olevat taajuuskaistat eivät ole identtisiä.

5 WAN (4G ja 5G)

Viime vuodet ovat olleet globaalien mobiilidatan käyttäjille haastavia. 3G-verkot on lopetettu laajalti, ja myös ”perälautana” kenties pidetty 2G (GSM) tekniikka on purettu taajuuksien vapauttamiseksi. Tämä on tehnyt monista modeemeista käyttökelvottomia, ja vaikutuksia on näkynyt myös kuluttajapuolelle joidenkin autojen verkkoyhteyksien loppuessa.

WAN eli mobiilidata on myös haastava toteuttaa, koska tekniikan lisäksi on huolehdittava liittymien (eli SIM-korttien) hallinnasta. Suomesta hankitut liittymät eivät välttämättä toimi Euroopan ulkopuolella halutusti, tai liian kauan roaming-statuksella toimiva liittymä saatetaan estää muutaman kuukauden jälkeen siitä sen kummemmin ilmoittamatta.

Liittymien hallintaan erikoistuneita yrityksiä onneksi on, mutta palveluista joutuu tietenkin maksamaan ja yritysten tulisi nimetä joku henkilö seuraamaan ja hallinnoimaan näitä liittymiä, mikä on iso muutos.

5G on teknologia, jota hehkutetaan kovasti. Se on automaatiomielessä kuitenkin mielestäni tarpeeton. 4G on riittävän hyvä kaikkiin sovelluksiin.

5G:n yhteydessä on muistettava, että usealla taholla on iso taloudellinen intressi laajentaa sen käyttöä. Laitetoimittajat myyvät mielellään infraa, ja teleoperaattorit haluavat myydä liittymän joka laitteeseen. 5G:n yhteydessä mainostetaan myös usein kaikkia hyviä ominaisuuksia kerralla, vaikka ne eivät onnistukaan yhtä aikaa.

Leevi Lignell*, Minh Tran, and Tomi Roinila

Optimized Charging of Li-Ion Batteries by Using Adaptive Impedance-Based Approach

Abstract: Decreasing the charging time of Lithium-ion (Li-ion) batteries is essential for modern energy applications. However, significant challenges arise in balancing charging speed with safety and longevity. This study investigates the potential of real-time battery impedance measurements for controlled charging in Li-ion batteries. By integrating real-time data into adaptive charging algorithms, charging is optimized for safety, efficiency, and longevity. Experimental validation highlights the feasibility of these methods while identifying challenges such as computational demands and sensitivity to noise.

Keywords: Adaptive charging, Lithium-ion batteries, Electrochemical impedance spectroscopy

*Corresponding Author: **Leevi Lignell:** Tampere University, E-mail: leevi.lignell@tuni.fi

Minh Tran: Tampere University, E-mail: minh.tran@tuni.fi

Tomi Roinila: Tampere University, E-mail: tomi.roinila@tuni.fi

1 Introduction

Fast charging is a critical feature in Li-ion battery applications, particularly in applications like electric vehicles, where long charging times hinder widespread adoption. Conventional fast-charging techniques such as constant-current constant-voltage (CC-CV) charging often operate without real-time insights into the battery's dynamic state, increasing the risk of overcharging, overheating, and accelerated aging [1]. To overcome these limitations, there is a need for advanced charging control that integrate real-time diagnostics to ensure optimal charging performance while preserving battery health.

Impedance measurement has been recognized as a valuable diagnostic tool for assessing the internal state of Li-ion batteries, providing insights into parameters such as state of charge (SOC), state of health (SOH), and thermal conditions. However, traditional impedance measurement techniques, such as electrochemical impedance spectroscopy (EIS), are time-consuming and unsuitable for real-time applications. Recent advancements in rapid impedance measurement methods, including binary broadband perturbation and Fourier analysis, offer the potential to monitor battery

impedance in real-time with high accuracy and minimal computational burden [2].

In this study, we investigate the application possibilities of real-time impedance-based methods for controlling fast charging of Li-ion batteries. By exploring the integration of binary broadband perturbation and Fourier techniques into fast charging protocols, this work aims to assess their feasibility and potential benefits.

2 Theory and Methods

Lithium plating in Li-ion batteries is a chemical process that occurs during charging when the intercalation of lithium ions into the electrode material is incomplete, causing metallic lithium to deposit on the electrode's surface. This phenomenon poses a significant risk, especially during fast charging, where high current densities increase the likelihood of plating. If this lithium deposition continues to grow within the solid-electrolyte interphase (SEI) layer, it can penetrate into the electrolyte, resulting in irreversible lithium loss and a subsequent decrease in battery capacity [1].

Lithium plating can be mitigated by employing pulse charging methods [3]. The characteristics of the ripple are defined by its time-domain shape (e.g., square, sinusoidal, triangular), amplitude, and frequency. The ripple frequency has been identified as the most critical factor influencing the performance of pulse charging methods [3]. An optimally selected ripple frequency can reduce charging time, enhance charging efficiency, and minimize battery degradation.

The optimal frequency of the pulse charging ripple, f_{opt} , can be determined by utilizing the internal impedance of the Li-ion battery cell. The frequency f_{opt} corresponds to the point where the imaginary part of the battery impedance, Z_{batt} is zero i.e. where the phase shift of the impedance is 0° [3]. The impedance can be rapidly measured in real time by applying broadband perturbations and Fourier techniques [4].

3 Experiments

Fig. 1 shows the measurement setup applied in the work. A commercial Li-ion battery was charged both by the pulse charging method and conventional CC-CV charging method. The experiments were conducted using a bi-directional switch-mode power supply (Kepco BOP 50-20MG) to inject current into the Li-ion battery cell. Excitation generation and measurements were carried out using a Nidaq USB-6363 measurement card. The cell voltage was measured directly at the battery terminals, while the current was measured using a Tektronix 312A Hall-effect current sensor.

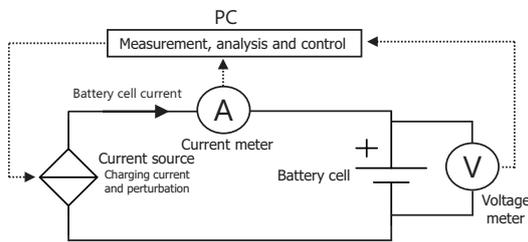


Fig. 1. Schematic of the measurement set-up.

The Li-ion battery cell was first charged from 0 % SOC to 50 % SOC using the CC-CV method with a current of 0.88 A. Then, the battery battery was recharged and charged again by the pulse charging method using a square wave pulse with a 50 % duty cycle. The peak charging current was set to 1.76 A to ensure a similar effective current compared to the CC-CV method. The optimal pulse charging frequency, f_{opt} , was determined through online battery-impedance measurements conducted with a 0.88 A load, with measurements taken at every 10 % SOC increment. The impedance was measured using a wideband technique as described in [4]. The initial pulse charging frequency was determined by measuring the battery impedance at 0 % SOC while the cell was at rest.

In the pulse charging experiment, a total of five different f_{opt} values (416 Hz, 679 Hz, 643 Hz, 802 Hz, and 183 Hz) were used during each stage of the charging intervals (0 %–10 %, 10 %–20 %, 20 %–30 %, 30 %–40 %, 40 %–50 %), respectively. The impedance measured at 30 % SOC, along with the determined f_{opt} is shown in Fig. 2.

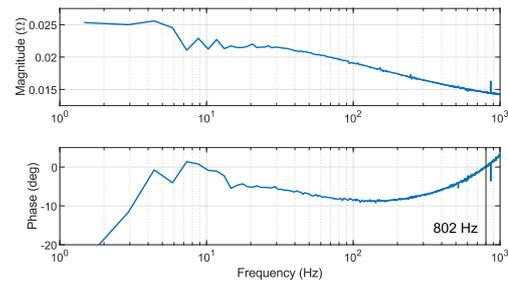


Fig. 2. Battery-impedance measured at 30% SOC presented as a Bode plot. The value of f_{opt} marked at 802 Hz.

No significant differences were observed in the charging times, as the pulse charging method was only 0.6 % faster than the CC-CV charging method. However, the pulse charging method offered other advantages, primarily in reducing battery degradation and improving efficiency. By applying intermittent pulses of current, pulse charging allows for cooling periods that reduce heat generation and thermal stress, mitigating factors such as lithium plating and capacity fade. Additionally, the method enhances Li-ion diffusion within the battery, promoting a more uniform charge distribution and optimizing internal impedance. These features not only contribute to improved battery longevity but also enable safer and potentially faster charging without compromising the battery’s health. Studies demonstrated that the use of wideband techniques to obtain battery impedance in real time can significantly improve the efficiency of the pulse charging method by introducing adaptivity to its operation.

References

- [1] F. Katzer, P. Möhle, M. Schamel, and M. A. Danzer, "Adaptive fast charging control using impedance-based detection of lithium deposition," *Journal of Power Sources*, vol. 555, 10 pages, 2023.
- [2] M. Tran, L. Lignell, J. Sihvo and T. Roinila, "Implementation Techniques for Online Impedance Measurement of Li-Ion Batteries", in *Proc. IEEE Energy Conversion Congress and Exposition*, pp. 168-173, 2023.
- [3] W. Vermeer, M. Stecca, G. R. C. Mouli and P. Bauer, "A Critical Review on The Effects of Pulse Charging of Li-ion Batteries", in *Proc. IEEE International Power Electronics and Motion Control Conference*, pp. 217-22, 2021.
- [4] M. Tran and T. Roinila, "Online Impedance Measurement of Lithium-Ion Battery: Applying Broadband Injection with Specified Fourier Amplitude Spectrum", *IEEE Trans. on Industry Applications*, vol. 59, issue 5, pp. 6580-6588, 2023.

Alex Kanerva*, Teijo Juntunen, Antti Ranta, Matti Vilkkö, Sami Repo, and David Hästbacka

Defining Energy Flexibility for Energy-intensive Industrial Processes

Abstract: This paper aims to propose a definition for the energy flexibility of energy-intensive industrial processes. Current research on this topic lacks an ambiguous definition for flexibility. In the literature, flexibility has been reviewed from different viewpoints and, therefore, does not give a comprehensive overall view. This lack of clarity poses challenges for industries to realize the flexibility potential of their processes. The paper begins with a review of existing research on industrial process flexibility, followed by presenting an alternative methodology. Flexibility is categorized into three core components: resources, services, and products. Flexibility resources represent the sources of flexibility; flexibility services provide abstract definitions to utilize these resources for specific purposes; and flexibility products offer mechanisms for trading and contracting services, such as through pricing schemes. To demonstrate the applicability of the proposed definition, two real-world case studies are presented. The first involves a wastewater treatment plant in Greece, where flexibility resources, potential services and relevant products are evaluated as part of a flexibility audit. The second use case focuses on a glass processing plant, analyzing the same aspects to demonstrate the versatility of the methodology. The novelty of this work lies in its structured methodology for defining flexibility and its practical application to diverse industrial scenarios, bridging the gap between theoretical frameworks and real-world operations.

Keywords: Flexibility, flexibility resource, flexibility service, flexibility product

***Corresponding Author: Alex Kanerva:** Tampere University, E-mail: alex.kanerva@tuni.fi

Teijo Juntunen: Tampere University, E-mail: teijo.juntunen@tuni.fi

Antti Ranta: Tampere University, E-Mail: antti.ranta@tuni.fi

Matti Vilkkö: Tampere University, E-mail: matti.vilkkö@tuni.fi

Sami Repo: Tampere University, E-mail: sami.repo@tuni.fi

David Hästbacka: Tampere University, E-mail: david.hastbacka@tuni.fi

1 Introduction

The industrial sector has been slow at adapting to changes in the energy system, despite such adaptation needed to meet the target of net zero emissions in the European Union by 2050, as outlined in the European Green Deal [1]. Historically, energy production has been designed to meet the demand. However, the growing penetration of variable renewable energy sources (VRESs) in the power system has introduced intermittency in energy generation, highlighting the necessity for demand-side flexibility. Addressing these challenges requires comprehensive changes to the power system, with industrial sector flexibility identified as a critical component of the solution [2]. In a 2020 report by the International Energy Agency (IEA) it is estimated that less than 2% of global flexibility potential is currently being utilized [3].

Energy-intensive industries (EIIs) are characterized by large energy consumption as a part of their operation [4]. These processes span various activities, including data processing, storage, and transmission in data centers; product manufacturing; food and material processing; and wastewater treatment. Due to their inherently high energy and power demands [5], EIIs present both challenges and opportunities in the context of integrating flexibility into the power system.

This paper seeks to establish a generalized definition of industrial process flexibility that can be applied across diverse use cases. The methodologies proposed for defining flexibility are reviewed, and two example use cases are presented to demonstrate the practical application of the developed definition. The results include characterization of the flexibility resources in the aforementioned industrial processes and an exploration of their utilization potential.

The scope of this paper is limited to active power-related flexibility. Issues related to reactive power, flexibility verification, and services associated with power quality are beyond the scope of this work.

2 Background

Research on the flexibility of energy-intensive industries (EIIs) has gained increasing attention in recent years. In some papers the energy flexibility of industrial processes has been evaluated [5, 6], while in others exploitation of the profit potential of industrial process flexibility in day-ahead (DA) and intraday (ID) markets [7] is discussed. In [8] the role of flexibility in balancing markets has been discussed. A review article examining research on industrial process flexibility up to 2019 [9] highlighted several areas requiring further exploration. These include the impact of flexibility decisions on entire production lines, the development of industry-specific frameworks, and the adoption of simulation-based approaches. Additionally, a notable research gap exists in understanding the information flow of energy flexibility between an EII's energy management system and its process optimization agents.

Flexibility is often conflated with related terms such as demand-side response (DSR), demand response, demand-side management, flexible generation, and energy storage [10]. While these concepts are integral to the broader discussion, they represent specific facets of flexibility rather than capturing its full scope. Consequently, these terms describe distinct areas of flexibility but fail to encompass the concept in its entirety.

Therefore, it is important to form a clear and comprehensive definition of energy flexibility. Such definition must include the identification of flexibility resources, the services these resources can provide, and the various flexibility products available. This approach ensures that the concept is sufficiently broad to encompass its diverse applications while maintaining the precision needed for practical implementation.

3 Aims

This paper aims to establish a clear and unambiguous definition of flexibility and demonstrate its practical application through two example use cases: the wastewater treatment plant (WWTP) aeration process and a glass processing plant. Flexibility is systematically categorized into three key components: resources, services, and products. The characteristics of these categories are analyzed and presented in detail.

The methodology involves identifying flexibility resources within the processes, determining potential services these resources can provide, and subsequently ex-

ploring possible products by examining the flexibility marketplaces of the process-respective countries as well as novel marketplaces. Additionally, potential challenges in utilizing flexibility in industrial processes and research gaps are discussed.

4 Materials and Methods

In this study, flexibility is categorized into three distinct components: flexibility resources, flexibility services, and flexibility products. This categorization provides a structured framework for evaluating and understanding flexibility in industrial processes. Flexibility taxonomy is visualized in figure 1.

4.1 Flexibility resources

Flexibility resources serve as the source of flexibility, enabling the provision of flexibility services. These resources must possess "the ability to change or modify their routine operation for a limited duration in response to external service request signals, without inducing unplanned disruptions" [10]. Examples of flexibility resources include power system operations, power system assets, loads, energy storage assets, and generators.

4.2 Flexibility services

Flexibility services describe the utilization of flexibility resources for specific purposes. A single flexibility resource may provide multiple services, and the definitions of these services should be independent of the individual resources. This ensures that future flexibility resources can seamlessly integrate, avoiding developmental barriers and enabling fair market participation.

Flexibility services encompass a wide range of applications, such as peak shaving, energy savings, and balance management. Flexibility resources, such as combined heat and power (CHP) plants, can simultaneously provide multiple services. Additionally, the aggregation of multiple flexibility resources can facilitate service provision, further enhancing the overall flexibility of the power system.

4.3 Flexibility products

Flexibility products represent the procurement mechanisms for flexibility services and are typically remunerated. These products are not mandated by grid codes but are developed to address specific system needs. A single flexibility product may be provided by multiple flexibility services and can be utilized to fulfill various technical challenges. For instance, an mFRR product could simultaneously address frequency control and congestion management [11].

The design and development of flexibility products require clear specifications of system operator needs to ensure their effective application. Flexibility products play a vital role in maintaining the reliable operation of the power system. For portfolio optimization, balancing, and congestion management, flexibility products should be designed to enable efficient allocation of flexibility and maximize its overall value [12].

Acknowledgement

This project has received funding from the European Union's Horizon EUROPE research and innovation programme under Grant Agreement No 101058174 "TRINEFLEX".

References

- [1] European Green Deal. 2022.
URL <https://www.consilium.europa.eu/en/policies/green-deal/>
- [2] Golmohamadi H. Demand-Side Flexibility in Power Systems: A Survey of Residential, Industrial, Commercial, and Agricultural Sectors. *Sustainability (Basel, Switzerland)*. 2022; 14(13):7916–. Place: Basel Publisher: MDPI AG.
- [3] Industry – Analysis.
URL <https://www.iea.org/reports/industry>
- [4] Definition: energy-intensive industry from 42 USC § 17111(a)(2) | LII / Legal Information Institute.
URL https://www.law.cornell.edu/definitions/uscode.php?width=840&height=800&iframe=true&def_id=42-USC-802996646-2096245136&term_occur=1&term_src=title:42:chapter:152:subchapter:III:part:D:section:17111
- [5] Ledur S, Molinier R, Sossan F, Alais JC, El Alaoui Faris MD, Kariniotakis G. Identification and quantification of the flexibility potential of a complex industrial process for ancillary services provision. *Electric power systems research*. 2022;212:108396–. Publisher: Elsevier B.V.
- [6] Uhlig B, Kloock M, Mennenga M, Herrmann C. Simulation-based energy flexibility analysis of manufacturing process

- chains: heat treatment in a foundry. *Procedia CIRP*. 2022; 107:1379–1384. Publisher: Elsevier B.V.
- [7] Gernscheid SHM, Mitsos A, Dahmen M. Demand response potential of industrial processes considering uncertain short-term electricity prices. *AIChE journal*. 2022;68(11):n/a. Place: Hoboken, USA Publisher: John Wiley & Sons, Inc.
- [8] Björkqvist T, Hildén A, Majanne Y, Vilkkio M, Pakonen P, Tuovinen O. Optimized utilization of groundwood lines with single layer grinding surfaces for pulp production and electrical grid stabilization;.
- [9] Howard DA, Ma Z, Jørgensen BN. Evaluation of Industrial Energy Flexibility Potential: A Scoping Review. In: *2021 22nd IEEE International Conference on Industrial Technology (ICIT)*, vol. 1. 2021; pp. 1074–1079.
- [10] Degefa MZ, Sperstad IB, Sæle H. Comprehensive classifications and characterizations of power system flexibility resources. *Electric power systems research*. 2021;194:107022–. Place: Amsterdam Publisher: Elsevier B.V.
- [11] Dominguez F, Willeghems G, Gerard H, Tzoumpas A, Drivakou K, Villar J, Augusto C, Cruz JM, Damas C, Dikaiakos C, Gandhi S, Lipari G. A set of standardised products for system services in the TSO-DSO-consumer value chain. 2020;.
- [12] A toolbox for TSOs and DSOs to make use of new system and grid services.
URL <https://www.entsoe.eu/news/2019/04/16/a-toolbox-for-tsos-and-dsos-to-make-use-of-new-system-and-grid-services/>

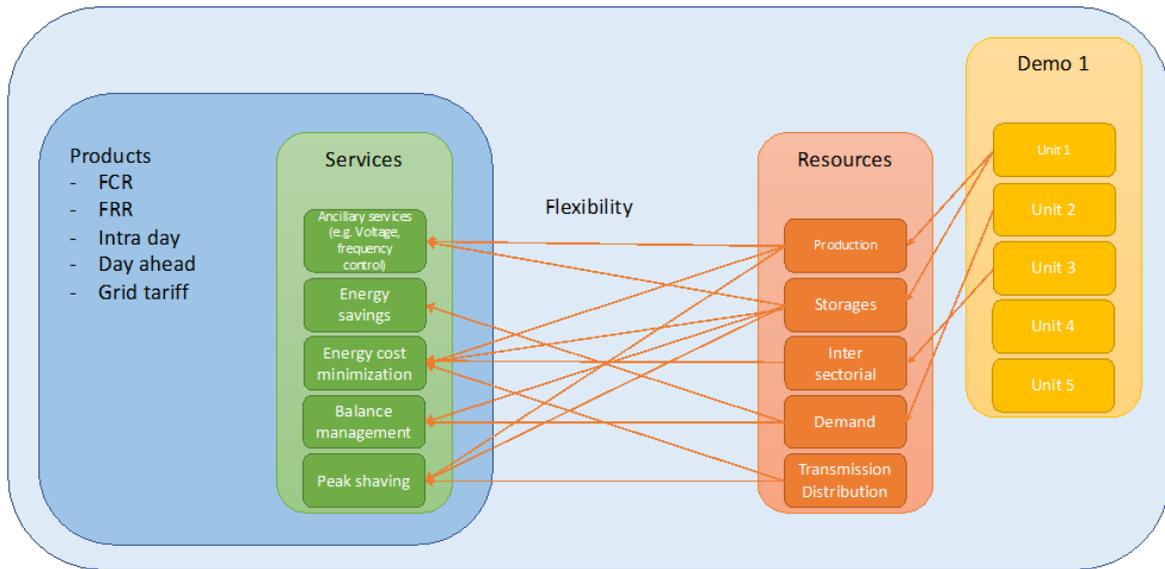


Fig. 1. Visual representation of flexibility taxonomy

Niko Siltala* and Alekski Partanen

Accuracy Evaluation of Landmark-based Visual Positioning of a Collaborative Robot

Abstract: This paper presents research work completed for the TeknoHUB project. The research problem is how accurately a robot can be positioned using a landmark (visual tag) and an optical sensor. An example of this use case would be a machine tending solution, where the robot cell frequently switches its operating position between workstations. The goal of this research is to localize a landmark fixed to a rigid body, such as a machine or a fixture, using a wrist camera attached to the robot, and then measure the error of optical localization based on the camera data. This information is then used to reposition the working frame of the application. This research studies and reports how accurately this can be performed on the selected test case.

Keywords: vision based positioning, landmark, visual tag, collaborative robot, accuracy measurement

*Corresponding Author: **Niko Siltala:** Tampere University, E-mail: niko.siltala@tuni.fi
Alekski Partanen: Enico Oy, E-mail: aleksi.partanen@enico.fi

1 Background

Collaborative robots are increasingly used in changing working locations at factories. Temporal setups would benefit if the robot can be automatically positioned accurately relative to the process, e.g., in a machine tending solution. There are a few ways to implement this. One is to have mechanical positioning with accurate position features on the floor or flanges in the machine. Another method uses landmarks (or visual tags) and cameras as positioning features. This paper focuses on the latter and its accuracy evaluation in the selected test case.

2 Aims

The research questions for this case study are:

RQ1. How accurately can a landmark be localized for the purposes of optical positioning of the collaborative robot?

RQ2. What are the main challenges and error sources of landmark based optical positioning?

3 Materials and Methods

This experimental research studies the 3D positioning accuracy of collaborative robot with a landmark and 2D camera. The hardware for this research consists of a collaborative robot, vision system, measurement tools, and a framework for optical positioning of the robot. The robot used in this research is Doosan M1013 collaborative robot, capable of handling weights up to 10 kg with a 1300 mm reach [1]. The robot is equipped with a Smart Vision Module (SVM), which operates as the vision system for this research. This wrist camera has a resolution of 2,5 megapixels and is equipped with an internal LED lighting system [2].

The wrist camera of the robot is used to localize a landmark, which is used as an origin point (frame) in relation to the other positioning features. The landmark is a small board with distinguishable features, which can be used to determine the location, orientation, and distance of the landmark in a 2D image. Thus, the pose of landmark can be defined in relation to pose of SVM and eventually in the robot's coordinate system.

The positioning target and its positioning features used in this research are three metal balls, which are attached firmly into a rigid metal frame. The landmark is attached into the same frame with an aluminum profile. See fig. 1. The goal is to place the whole target frame within the reach of the robot, where it can effortlessly localize the landmark from Field of View (FOV) of the SVM, and reach all three positioning features.

The measurement procedure for the research is as follows. First, the frame is placed in a new pose and rigidly mounted on the robot table. Then, at the beginning of the robot program, the robot first moves to the imaging pose and localizes the landmark using the SVM. It extracts the coordinates of the landmark origin to the robot program. The robot is programmed to move next to the ground truth coordinates of each positioning target relative to the found origin of the landmark. The robot approaches each of the position-

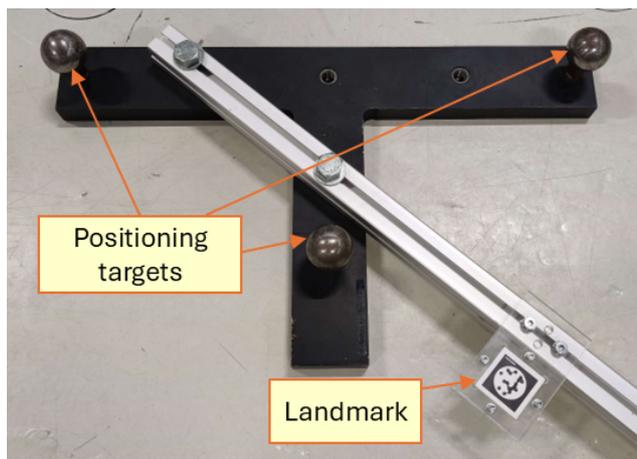


Fig. 1. Target frame with a landmark and positioning targets

ing targets five times from above before moving on to the next one. In an ideal world, the robot's measurement tool, mounted on the flange of the robot, would always have the same position (pressure) applied to all the measurement probes, considering that there are no inaccuracies. The position applied to the measurement probes can be used to measure the inaccuracy of the optical positioning.

Two different level measurement tools are used for the research. First, the reference distances between the landmark and the centers of all metal balls (D 50 mm) need to be known (i.e., the ground truth), which can then be utilized to assess the optical positioning capabilities of the robot and the vision system. This is completed with a coordinate measurement device, which in this study is the 6-axis Romer arm from Hexagon Metrology with a touching probe. It is capable of ± 0.029 mm probing accuracy [3]. The second is the robot's measurement tool implemented with the Sylvac E25 system, which consists of three measurement probes and signal processing devices. One probe is capable of measurement accuracy of 1.5 m in one Degrees of Freedom (DOF). The three probes are mounted perpendicular to each other on a frame, which is mounted on the robot's tool flange, forming a measuring tool for the robot (Fig. 2). The tool itself is also measured with the Romer arm to find the exact positions and orientations between the mounting tool flange and each of the three probes. This information was used to define more accurately the Tool Centre Point (TCP) for the robot tool. Why we ended up with this approach will be explained in the full paper. The setup, including the camera and tools, required different calibration procedures. These are also discussed in the full paper.

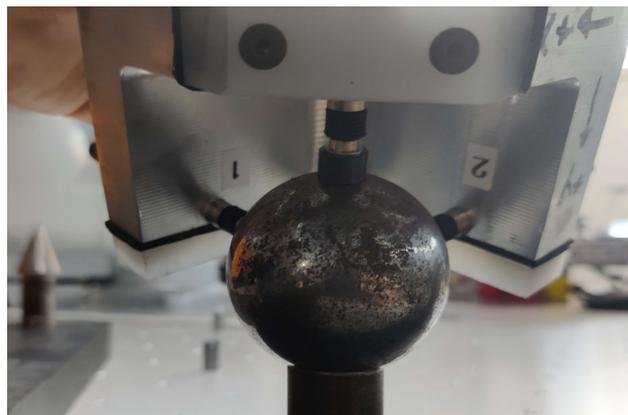


Fig. 2. Robot's measurement tool aligned over a position target

4 Results

The target frame was measured in six different poses under the robot. The measurements were executed five times in each of the target frame poses, i.e., the full measurement procedure was repeated five times.

Measured results include 1) the pose (position and rotation) of the landmark found from the captured image; and 2) both relative and absolute errors calculated at each position target. Relative error is represented with the range across the five measurement iterations. Absolute error is correspondingly represented as the Mean Absolute Error (MAE) within the iterations.

The research provided quantifiable data that could directly be linked to RQ1, for which the research provided results from several different configurations. The landmark can be located with an accuracy of ± 0.1 mm or better in the XY-plane and slightly less in the Z-plane. However, the locating procedure had two outliers where these figures were exceeded. The results show that, within the scope of this research, optical localization was completed with varying results. There were two notable observations that could explain these results. First, the localizations where the landmark was near the center of the camera FOV seemed to yield better results. This could be explained by the camera calibration, which was better at estimating depth at the center of the FOV compared to the edges of the FOV. Secondly, the two balls near the landmark (366.12 mm distance for ball 1 and 344.37 mm for ball 2) had better results than the one ball further from the landmark (718.64 mm for ball 3). Overall, the results from all cases combined resulted in an MAE of 0.5 to 3.0 mm.

Mats Friman*

Tuning of Control Loops with Valve Problems

Abstract: Control valve non-linearities may cause control loop oscillations. Usually, it is not possible to instantly replace a valve in operation just because it causes oscillations in the process, but with proper controller tuning we can minimize valve wear and reduce oscillation amplitudes, and sometimes even eliminate the oscillations. We discuss two major valve non-linearities, backlash and stick-slip, and how to tune the PID controller for such valves.

Keywords: backlash, stick-slip, oscillations, PID tuning

*Corresponding Author: Valmet Automation, E-mail: firstname.lastname@valmet.com

1 Introduction

Control valves play a crucial role in the process industry, regulating the flow of fluids, such as gases, liquids, and slurries. These valves are essential for maintaining the desired process conditions, such as pressure, temperature, and flow rate, ensuring the efficient and safe operation of industrial processes.

An industrial control valve package consists of a valve body, a pneumatic actuator, and a valve positioner. All these components consist of mechanical part that are subject to wear and dirt (Kirmanen et al. 1997).

Control valves can encounter several problems that may affect their performance and reliability. Example problems include increased friction in valve body and actuator, pneumatic leakage in actuator and positioner, wear in mechanical parts, and design problems, most commonly improper sizing of valve or actuator.

Valve problems frequently cause oscillations in the PID control loop. Instant replacement of a faulty valve because of loop oscillations is usually not an option. Instead, we can minimize the damage by re-tuning the PID controller. In this study we discuss how to decrease the oscillation amplitudes (in both process value (PV) and control output (CO)) to minimize impact of oscillations on the process. Moreover, increasing the period of oscillations reduces valve wear.

To our knowledge, PID tuning recommendations for faulty valves have not been previously reported. Still, we believe that special tuning recommendations for faulty valves are useful and that there is a great possibility to stabilize oscillating processes and improve quality and economic performance in the entire process industry.

2 Modeling Common Valve Non-Linearities

To model non-ideal valve behavior, we consider two non-linearities: 1) backlash and 2) stick-slip. These non-linearities are illustrated in Figure 1 below.

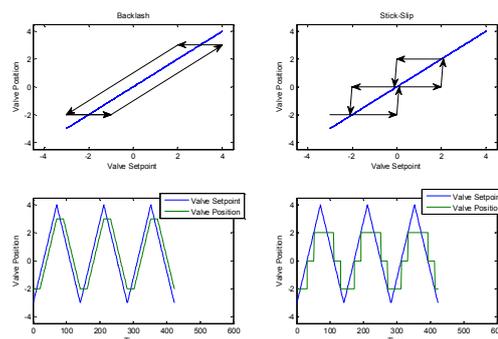


Figure 1. Illustration of backlash (left) and stick-slip motion(right).

Stick-slip is useful to model sticky valves with high friction. In that case, valve positioner must increase actuator pressure extensively to move the valve. Stick-slip movement makes it impossible to position the valve properly. Valve stick-slip is also useful to model a control valve with an undersized actuator. On the other hand, valve problems where friction is not an issue are best modeled with simple backlash. A very common example is a worn-out link between valve shaft and valve body of a rotary valve. Such a case is best modeled using backlash.

Usually, the process dynamics of typical process industry controls are well modeled using simple linear transfer functions. However, control valves with pneumatic actuators don't show such an ideal behavior. For example, valve positioners typically have

a dead-band specification (defined as how much valve setpoint can change before we can expect valve movement) of 0.2% (Valmet Flow Control, 2024). Hence, PID tuning recommendations based on ideal linear transfer functions, are not necessarily optimal when we have a control valve in the loop.

3 Impact of Valve Non-Linearities on Control Loop Performance

Next, we discuss how a linear transfer function (describing flow, level, pressure, and temperature controls) controlled by a PID controller behaves when we have stick-slip or backlash in the control valve.

A fundamental question is: does backlash or stick-slip in the valve cause control loop oscillations?

For the stick-slip case the answer is quite straightforward: yes, the loop will oscillate with an amplitude and period that depends on amount of stick-slip, the PID controller tuning parameters, and process dynamics.

For the backlash case, the situation depends on the PID controller tuning parameters and process dynamics: we may see oscillations in the loop, or we may get a stable loop.

As an example, consider a simulated level control loop with some 1% backlash in the control valve. We model the level using a first-order-plus-deadtime model (with gain $K=40$, time constant: $T=600$, dead time $L=6$) and employ a PI controller (with gain $K_p=1.0$ & integration time $T_i=60$, tuned by SIMC rules, Grimholt and Skogestad, 2012). Simulations suggest that this system oscillates with a period of 260 and PV oscillation amplitude 0.54, as illustrated in Figure 2 (green lines).

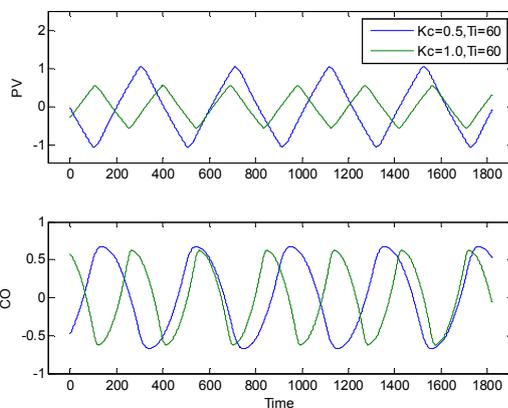


Figure 2. Example control loop oscillating because of backlash in valve. Original tuning in green and detuned (gain 50% of original) loop in blue.

At this point a natural question is: how should we tune the PI controller to reduce impact of oscillation generally on the process (to reduce PV amplitude), and to reduce valve wear (by increasing period of oscillation and decreasing amplitude of CO)? A surprising result, even to experienced control engineers, is that detuning controller gain by 50% ($K_p=1.0 \rightarrow 0.5$) is a bad option, as it *increases* the amplitude of PV oscillations, in this case by 93% (blue trends in Figure 2). A tighter tuning ($K_p=1.0 \rightarrow 1.5$) decreases the PV amplitude, but with a cost of increased valve wear due to faster oscillations (not shown).

Table 1 summarizes impact of some PI tuning changes to the level example, where we have simulated a 50% increase/decrease of PI controller gain, and a 100% increase of PI controller integration time.

Table 1. Impact of PI tuning on example backlash loop. Green color indicates improved and red worse performance compared to original tuning.

Tuning	Period of Oscillation	PV Amplitude	CO Amplitude
Original	260	0.54	0.66
$0.5 \times K_p$	364	1.04	0.72
$1.5 \times K_p$	210	0.37	0.64
$2 \times T_i$	465	0.49	0.58
$1.5 \times K_p, 2 \times T_i$	383	0.34	0.57

In this presentation we will on a general level discuss how to tune a PID controller to reduce valve wear and to avoid oscillations when we have stick-slip or backlash in the loop. Moreover, we also discuss simple modifications to the control loop. For example, adding a deadband in the PI controller (i.e. to allow a certain controller error) may sometimes stabilize an oscillating loop.

4 References

Grimholt, C. and Skogestad, S.. Optimal PI-Control and Verification of the SIMC Tuning Rule. IFAC Conference on Advances in PID Control, PID'12, Brescia Italy. 2012.

Kirmanen J., Niemelä I., Pyötsiä J., Simula M., Hauhia M., Riihilahti J. The Flow Control Manual,.4th ed. Metso Automation. 1997.

Valmet Flow Control. Neles™ NDX™ intelligent valve controller, standard model. Technical Bulletin. 2024.

Esko K. Juuso

Varying time delays in intelligent steady state and dynamic models

Abstract: A widely applicable solution for nonlinear steady state and dynamic models is to use intelligent interactions which are theoretically supported by the expert knowledge. These models can be tuned by using measurement data. The problematic part to select data values for the variables. In many modelling cases, this important issue is left out by assuming that time delays do not have essential effects. The model tuning can be done but the recent measurements of some variables cannot have any effect on the result. The structure of the model should be the basis. In many cases, a data-driven analysis of the time delays is enough. More problematic are cases where time delays are varying with time. A typical situation is that time delay depends on the flow speed. If the flow is constant for long periods this can be handled with working points. The most difficult situation is if the flow is a control variable or a variable which is fluctuating strongly. The key is to take the system operation as it really is. In lumped parameter models, the time delay can be uncertain if the input contains effects of several time periods. The model can be based on tube operation. The system may need distributed parameter modelling. This paper uses nonlinear scaling in relating effective time delays with the flow in application cases.

Keywords: intelligent models, nonlinear systems, varying time delay

Esko K. Juuso, Control Engineering, Environmental and Chemical Engineering, Faculty of Technology, P.O.Box 4300, FI-90014 University of Oulu, Finland, E-mail: esko.juuso@oulu.fi

1 Introduction and background

Steady state intelligent models can be extended to nonlinear situations by combining nonlinear scaling and linear equations. Linear interactions work in wide areas if differences between operating situations are handled sufficiently well with the nonlinear scaling of the variables. In dynamic intelligent models, the equations are based on dynamic structures. In case-based models, equations are tried to keep unchanged. The nonlinear scaling is the key part of the models, which are called linguistic equation (LE) models. [1]

The linear interactions can be tuned by using measurement data or scaled values with the same methodologies. It is important to select the values of the variables by using correct time delays. Identification methodologies operate well around the operating points where the time delays can be identified as model parameters. Data-driven analysis of time delays operate well for linear models. The time delays depend on operating conditions. Case-based models can be used if there are longer periods of similar situations which depend on the levels of the inputs. Alternatively, different areas can be defined with specific working point variables.

Varying time delays have been quantitatively identified from measurement data with a sliding window based information theoretic delay estimation methodology. The same methodology was used in finding the varying time delay in the widely used benchmarking case: Box-Jenkins gas furnace data [2].

The tuning of the models becomes more difficult if the variables vary strongly with very short time periods. These situations are active in wastewater treatment processes where the input comes from different parts of the main process. The control should adapt fast to these changes. In solar thermal energy applications, very fast irradiance changes need strong changes of oil flow. The fast flows can be five times bigger than the low flows.

2 Aims

This research focuses on modelling of nonlinear processes which have strong variations of operating conditions. Varying time delays are used selecting the data for the tuning of the interactions.

3 Methods

The LE models combine nonlinear scaling and linear interactions.

Nonlinear scaling

The z-score based linear scaling solutions are extended to asymmetric nonlinear scaling functions consisting of

two second order polynomials. The parameters of the functions are defined with five parameters corresponding the operating point and four corner points of the feasible range. Feasible ranges are presented as trapezoidal membership functions defined by support and core areas. The scaling functions are monotonously increasing throughout the feasible ranges and the monotonous increase is certified by constraints [3]. In this study, the scaling functions are defined with five parameters corresponding scaled values $\{-2, -1, 0, 1, 2\}$.

Linear interactions

Interactions are represented with compact linear equations where each variable has an appropriate time delay to the calculation point. Monotonously increasing scaling functions allow the use of linear interactions for solving any variable from the other variables, i.e. they can be used as parts of a model, but also as model-based controllers or working point models for case-based models.

Dynamic structures

Linear interactions are used in steady-state models and can be extended to dynamic systems by parametric structures used in identification. If the nonlinear scaling operates well, only very simple structures are needed. In many applications, the new value of the simulated variable is calculated by using the current value of the simulated variable and delayed values of the control variables. The step size control is required for working with both fast and slow changes.

Case-based models

Variables, equation coefficients and scaling functions can be case specific. Cases are identified with fuzzy rules of input variables or additional working point variables. The nonlinear scaling used in LE models extend operating areas of the cases, which reduces the number of separate cases. Working point models can even remove separate cases by scaling the outputs.

Varying time delay

Modelling calculations are done for volumes whose sizes depend on the active flow. Time steps depend on the flow: time steps are short when the flow is fast and long when the flow is slow. The scaled values in the range $[-2, 2]$ are used in a very compact way:

$$D + F_s = 0$$

where D is the scaled time delay corresponding the scaled flow F_s . Nonlinear behaviour is handled with the scaling functions.

The scaling function of the flow is analysed from the measurement data for the scaled values $\{-2, -1, 0, 1, 2\}$. The corresponding time delays are estimated for these flow levels to define the scaling function for the time

delay. All scaling functions are continuous and monotonously increasing.

In each calculation point, the time delay is a weighted sum of the time delays of the previous steps. A compact solution is to use the time delays corresponding the flow measurements. Alternatively, the weighting can be based on the calculation steps adjusted with the step size control. The estimate of the time delay limits the number of time steps used in the summation. Only the new step calculations are needed and added in the stepwise array.

The simulation operates in the same way as the tuning presented above with one difference: the array of previous steps is constructed within the simulation run.

4 Case studies

Case studies start with a simple tube model. Uncertainties are studied in a lumped parameter model where the input contains inputs from several time steps. Distributed parameter models are needed if the inputs for calculation step are changing between the time steps of the measurements and the calculation step. Wastewater treatment processes and solar thermal energy collection processes are used as examples.

5 Conclusions

In wide operating areas, simulation models are improved by using more realistic time delays. The nonlinear scaling is needed for estimating the time delays from the flows. In future research, these methodologies can be extended to controller tuning and control.

References

- [1] Juuso EK. Integration of Intelligent Systems in Development of Smart Adaptive Systems. *International Journal of Approximate Reasoning*. 2004;35(3):307–337.
- [2] Ruusunen M. Signal Correlations in Biomass Combustion - an Information Theoretic Analysis. *Acta Univ Oulu C* 459, 2013. PhD Thesis.
- [3] Juuso EK. Nonlinearity Analysis of Variables for Modelling and Control. In 3rd SIMS EUROSIM 2024, September 11-12, 2024, Oulu, Finland, p. 481-487. doi: 10.3384/ecp212.065.

Jarkko Kotaniemi* and Janne Saukkoriipi and Tuomas Seppälä

Robot Deburring Path Generation Based on a 3D Point Cloud

Abstract: Modern manufacturing demands flexibility, customization, and efficiency in traditionally rigid processes. Digital automation has been increasingly more prevalent. With small batch sizes, increased automation means that offline programming and planning of tool paths takes a larger portion of work for each part. We present a method of creating a robot path for deburring an oxy-fuel cut part using a 3D point cloud. This method allows for faster automation of a common finishing step in parts manufacturing without the use of a CAD model or offline programming. Experiments show that our method can be used to easily generate a deburring path on a part that is randomly placed in the work area.

Keywords: point cloud, robot path generation, deburring

***Corresponding Author: Jarkko Kotaniemi:** VTT Technical Research Centre of Finland, E-mail: jarkko.kotaniemi@vtt.fi

Janne Saukkoriipi: VTT Technical Research Centre of Finland, E-mail: janne.saukkoriipi@vtt.fi

Tuomas Seppälä: VTT Technical Research Centre of Finland, E-mail: tuomas.seppala@vtt.fi

1 Introduction

With ever-increasing demands for agility and flexibility, robotized manufacturing is facing challenges and barriers to the use of robots because; the high cost of engineering the work cells (i.e., the design, fabrication, and installation of jigs, fixtures, conveyors, and third-party sensors and software) [1]. Robot skills are high-level abstractions of tasks, that enable robots to perform complex operations like pick-and-place, grinding, or assembly with minimal low-level coding [2]. By leveraging skill programming, developers can streamline robot programming, enhance adaptability across various tasks, and accelerate deployment in dynamic environments.

3D cameras integrated with robotic systems are predominantly utilized for object localization and

quality control. Conventionally, object detection and localization are achieved using 3D point clouds, while the generation of robot paths continues to depend on CAD models and offline programming tools. In the method we present, CAD objects are not utilized, and robot paths are generated directly from the captured point cloud data.

2 3D Point Cloud Processing

Our point cloud processing is performed using in-house developed software, which requires a structured point cloud, the default output for 3D depth cameras. Initially, the software extracts surface segments by comparing the distances between neighboring points and the directions of their surface normals. Optionally some filtering can also be applied: removing the background (like the table) or decimation. Once the segments are extracted, inner and outer edge points are identified for each segment, separated into individual edges, and incorporated into the segment data. In this context, the outer edge defines the boundary between the plane and the burr. This edge is then analyzed to provide vertices. Due to the randomness of the burr lines, the shapes remain overly detailed. For robot deburring, it is only necessary to identify the main corners and disregard the irregularities of the burr line and thus require more filtering.



Fig. 1. Segmented edge and extracted vertices of the part. The edge is marked in red, and the vertices are marked in green.

Besides vertex extraction (Figure 1), more detailed analysis of the burr can also be performed. Information

such as the height of the burr can help determine which tool should be used for deburring. The burr in the object is calculated by analyzing the segment's neighborhood, identifying which unsegmented points are located above the surface, and calculating their distance from the segment plane. A minimum distance limit is recommended to eliminate noise in the segmentation and accurately recognize only the burrs (Figure 2).



Fig. 2. Detected burr is marked in yellow.

3 Robot Tool Path Generation

The extracted vertices of the part are used to generate the tool path for the deburring operation. Because of the uneven nature of the burr, there are quite many extra vertices even on a straight edge of the part which need to be filtered out. Using the Ramer–Douglas–Peucker (RDP) algorithm, the excess detail given by the vertices can be reduced to only the essential portions, which are the actual corner positions of the part. For effective deburring, it is crucial for the tool to follow the edge's direction. By aligning the tool's orientation to point toward the subsequent edge pose, the deburring process can be executed properly.

The path generation generates a path in JSON format that the robot can execute easily utilizing our robot skill-based programming system. The path was programmed so that it starts from the closest corner to the robot and operates in clockwise direction around the object.

4 Experimental Setup and Testing

The generated paths were implemented in our laboratory test facilities. The test objects were metal objects that had been cut and had burrs within them. As 3D camera we used Zivid2+ M60 model which represents the high-end of 3D cameras. 3D camera was placed in the environment and calibrated to the robot with methods presented in here [3]. The robot used in the tests was Universal robot's UR5 with a simple

pointer tool (Figure 3). The aim of this experiment was not to do actual deburring but to demonstrate the accuracy of the generated path.

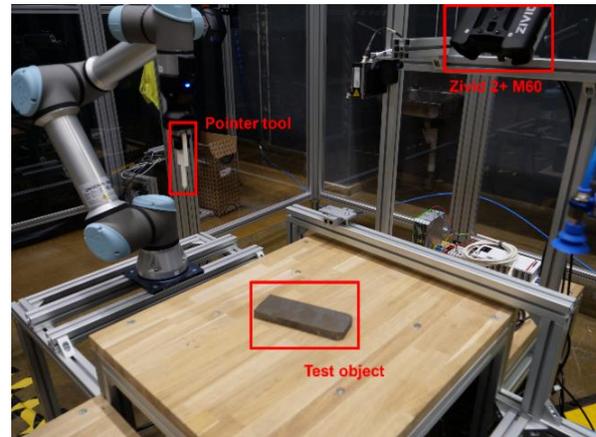


Fig. 3. Experimental setup with the tool, test object and camera marked.

5 References

- [1] J. Saukkoriipi, T. Heikkilä, J. Ahola, T. Seppälä and P. Isto, "Programming and control for skill-based robots" *Open Engineering*, vol. 10, no. 1, 2020, pp. 368-376. <https://doi.org/10.1515/eng-2020-0037>
- [2] T. Lohi, S. Soutukorva and T. Heikkilä, "Programming of Skill-Based Robots", *2024 IEEE 19th Conference on Industrial Electronics and Applications (ICIEA)*, Kristiansand, Norway, 2024, pp. 1-7, <https://doi.org/10.1109/ICIEA61579.2024.10664981>
- [3] T. Heikkilä, J. M. Ahola, J. Koskinen and T. Seppälä, "Calibration procedures for object locating sensors in flexible robotized machining", *2014 IEEE/ASME 10th International Conference on Mechatronic and Embedded Systems and Applications (MESA)*, Senigallia, Italy, 2014, pp. 1-6, <https://doi.org/10.1109/MESA.2014.6935567>

Samuli Bergman*, Andreas Frejborg, Ferroman Engineering Oy, and Hans Aalto, Take Control Oy

Optimal control of fuel gas mixing systems

Abstract: There is an increasing need to design and analyze fuel gas mixing systems where a variety of gases are mixed in highly varying proportions in order to serve mixed gas users in different operating conditions. One source of high variability is electrolyzer-produced hydrogen, which may induce variations of 0 to 100% produced hydrogen depending on the power market situation.

Keywords: Gas mixing systems; gas quality control; Wobbe index

***Corresponding Author:** Samuli Bergman, Ferroman Engineering Oy,
E-mail: samuli.bergman@ferroman.com

1 Introduction

Mixing of fossil and/or non-fossil fuel gases for combustion in industrial systems, such as furnaces and boilers, is becoming more demanding as hydrogen comes into the picture. There is a fairly good coverage in literature on the subject of mixing small amounts of hydrogen into natural gas pipelines. A challenge case for an industrial gas mixing system and its control and optimization was presented by Ricker et. al. [1] for small amounts of hydrogen feed but with multiple combustible recycle gases with varying properties.

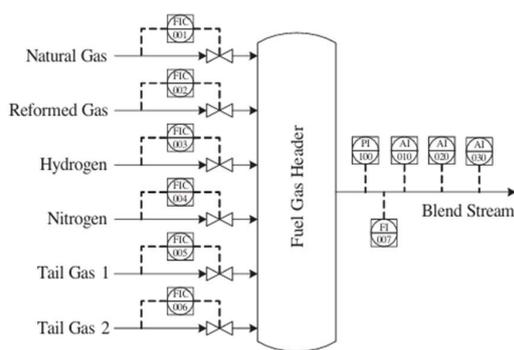


Figure 1. Gas mixing system, from [1]. Flow-controlled inlet gases and on-line property analyzers (AI) on the mixed gas outlet stream.

2 The role of hydrogen

Hydrogen provides a viable option to reduce fossil fuel gas usage in industrial heating systems. The technology and engineering challenges start from selecting proper materials for piping, mixing vessel, valves and instruments in order to minimize hydrogen escape. Safety is of very high priority in hydrogen service. If the hydrogen share must be allowed to vary in a wide range, even the extreme case 0...100%, the rangeability of control valves and gas flow meters must be secured either by finding such single devices with performance guarantee or designing parallel gas flow paths for small and large gas flows. Add to this the scenario of highly varying flow of the mixed gas, which is everyday routine in steel industry where the fuel gas consumption is highly periodic.

One reason for a high variability of the hydrogen content is generation of hydrogen with an electrolyzer for which production may depend on the power price – at low price the hydrogen generation is high and vice versa. The wider the allowed range of hydrogen generation, the better is the economics.

3 Wobbe index

The Wobbe index W of a gas is defined as:

$$W = \frac{LHV}{\sqrt{\rho/\rho_{AIR}}}$$

Where LHV is the lower heating value (MJ/kg) of the gas, ρ is the density of the gas and ρ_{AIR} is the density of air. The Wobbe index is commonly used as a measure of interchangeability of fuel gases with different compositions. The Wobbe index is one of several quality variables of the mixed gases which must be monitored for instance using a dedicated on-line Wobbe index analyzer in the mixed gas stream. It can also be calculated using the mass or volume fractions of inlet gases based on flow measurements and known heating values and densities of them. For instance, for a mixture of hydrogen (LHV₁, ρ_1) and natural gas (LHV₂, ρ_2) we can write, using molar masses M_1 and M_2 and M_{AIR} for the molar mass of air:

$$W = \frac{R * LHV_1 \rho_1 + (1 - R) * LHV_2 \rho_2}{\sqrt{[RM_1 + (1 - R)M_2]/M_{AIR}}}$$

Where R is the volume fraction of hydrogen and 1-R is the volume fraction of natural gas.

Plotting W as a function of R, we find a minimum point for R = 87 %, see figure 2. It is obvious that this minimum point challenges any closed loop control and/or optimization of W. As a minimum, process gain following is required, and automatic re-tuning if the measured or calculated W can be trusted.

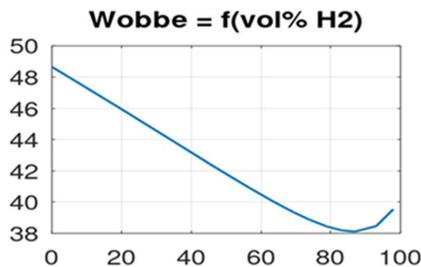


Figure 2. Wobbe index as a function of volumetric percentage of hydrogen.

4 Other mixed gas properties

Other important mixed gas properties include adiabatic flame temperature, flame speed and flammability limits, the latter playing an important role if air is one of the inlet gases. Air is sometimes used to decrease the Wobbe index when propane is one of the feed gases. Since a large fraction of hydrogen in the mixed gas increases the volumetric flow in the piping downstream the mixing vessel, some maximum limits of pipe speeds can be applied.

5 Optimal control

Energy balance, i.e. the total energy of inlet gases, must be equal to total consumed energy, averaged over some time period. Wobbe index may be required to be controlled to some target value or stay within some narrow min/max limits, but the other mixed gas properties can typically float between given minimum and maximum limits. If the number of inlet gases, N, is high enough to enable degrees of freedom for on-line optimization, a cost function:

$$J = \sum_{i=1}^N P_i F_i$$

can be minimized where P_i are gas prices (Eur/kg) and F_i are inlet gas flows (kg/h). CO₂ cost, which also depends on F_i can be added to the cost function.

6 Mixed gas distribution system

The mixed gas distribution system may be a complex pipe network with multiple branches and sub-branches. The changes in gas composition, initiated at the mixing station, propagate through the system partially as a “time constant” flow (single- or multiple capacity process) and partially as plug flow. This puts challenges on how to estimate the gas compositions at the gas user positions along the network.

7 Bibliography

[1] Ricker, N.L., C.J. Muller and I.K. Craig, Fuel gas blending benchmark for economic performance evaluation of advanced control and state estimation, *Journal of Process Control*, 22(2012), pp. 968-974.

Corresponding Author* and Second Author

Artificial Intelligence for Automation in Manufacturing: Advancing Sustainability and Profitability in Continuous Process Industries

Abstract: The integration of Artificial Intelligence (AI) into manufacturing has revolutionized continuous process industries by driving automation that balances sustainability with profitability. AI-powered solutions enable real-time monitoring, optimization, and predictive maintenance, reducing energy consumption, material waste, and operational downtime. By analyzing large volumes of process data, AI enhances process efficiency and product quality, while ensuring compliance with environmental standards. Continuous process industries, such as pulp and paper, petrochemicals, and steel manufacturing, can achieve substantial cost savings and carbon footprint reduction through intelligent automation. Despite the significant potential of AI, its adoption remains limited compared to hardware-centric upgrades, highlighting an untapped opportunity for industries to leverage software-driven innovations. This paper explores the transformative role of AI in automating complex manufacturing processes for enhanced sustainability and economic gains, emphasizing practical use cases and implementation strategies.

Keywords: AI, manufacturing automation, process optimization, sustainability, digital transformation

***Corresponding Author:** Hung Ta, E-mail: hung@greenfactory.ai

Second Authors: Roosa Peippo, E-mail: roosa@greenfactory.ai; Petteri Ormio, E-mail: petteri@greenfactory.ai

1 Introduction

The global manufacturing landscape is undergoing a profound transformation, with sustainability and operational efficiency emerging as critical imperatives for industries worldwide (Marco Taisch and David Romero, 2024). Continuous process industries, including pulp and paper, petrochemicals, and steel manufacturing, face unique challenges due to their high energy consumption, resource-intensive processes, and strict regulatory requirements. These industries

operate on a delicate balance, striving to reduce their environmental footprint while maintaining profitability and ensuring product quality.

The emergence of Artificial Intelligence (AI) technologies has opened new avenues for innovation in manufacturing (Matthew Finio and Amanda Downie, 2024). AI enables the seamless integration of real-time data from production processes, unlocking unprecedented potential for automation and optimization. Unlike traditional approaches to process control, which rely on predefined rules and manual interventions, AI systems dynamically adapt to changing conditions, allowing manufacturers to respond swiftly to variability in production parameters, resource availability, and market demands.

In this context, AI-powered solutions such as predictive maintenance, process optimization, and advanced quality control have demonstrated their ability to reduce energy consumption, minimize waste, and enhance operational reliability. For example, AI can predict equipment failures before they occur, optimize setpoints to achieve target product quality with minimal energy input, and ensure compliance with stringent environmental regulations (Mäki-Lohiluoma et al., 2021). These capabilities are particularly valuable in continuous process industries, where even minor inefficiencies can lead to substantial cost overruns and environmental impacts.

Despite the demonstrated potential of AI, its adoption in continuous process industries remains limited compared to hardware-centric innovations, such as advanced machinery or energy-efficient equipment upgrades (Henry Bristol et al., n.d.). The barriers to adoption are multifaceted, encompassing concerns about the complexity of AI systems, the need for data integration across legacy infrastructures, and the lack of skilled personnel to manage AI-driven operations. Overcoming these barriers requires not only technological innovation but also a strategic focus on change management, workforce development, and stakeholder collaboration.

By exploring the intersection of AI, automation, and sustainability, this paper aims to provide actionable insights for industry leaders, researchers, and policymakers. It underscores the urgency of embracing AI as a key enabler of sustainable manufacturing, while outlining practical steps to accelerate its adoption in continuous process industries.

2 AI-Driven Automation for Sustainable Manufacturing: Challenges and Opportunities

Background

Continuous process industries, such as pulp and paper, steel, and petrochemicals, are at the forefront of global manufacturing but face growing pressures to balance sustainability with profitability. These industries are characterized by high energy consumption, significant material waste, and stringent environmental regulations. Artificial Intelligence (AI) has emerged as a transformative force, enabling automation of complex manufacturing processes through real-time monitoring, predictive maintenance, and process optimization. AI-driven solutions dynamically adjust operations to reduce inefficiencies, improve product quality, and minimize resource use. However, despite its potential, AI adoption remains limited compared to traditional hardware upgrades due to challenges such as legacy system integration, workforce readiness, and high initial costs.

Aims

This research investigates the role of AI in automating manufacturing processes to enhance sustainability and profitability. The key objectives are:

- To explore the benefits of AI-driven automation in continuous process industries.
- To identify barriers and opportunities for AI adoption.
- To provide actionable strategies to accelerate the use of AI for sustainable and efficient manufacturing.

Methods

A mixed-methods approach was employed, combining:

- Analyzing current research and market trends to assess the state of AI adoption and its applications in manufacturing automation.
- Conducting semi-structured interviews with 15 industry experts, including CEOs, sustainability directors, digitalization advisors, and technical managers from the pulp and paper, steel, and petrochemical industries. Topics included:
 - o Current AI applications for manufacturing automation.
 - o Challenges in integrating AI with existing systems and workflows.
 - o Future opportunities for AI-driven

sustainability and efficiency.

Conclusions

AI-powered automation offers substantial benefits for continuous process industries:

- Enhanced Efficiency: Real-time optimization and predictive maintenance reduce downtime and improve production quality while cutting operational costs.
- Sustainability Gains: AI-driven solutions minimize energy consumption and material waste, reducing carbon emissions by up to 30% in early implementations.
- Adoption Challenges: Barriers include fragmented legacy systems, high implementation costs, and resistance to change within organizations.
- Actionable Strategies: Manufacturers can overcome these challenges by adopting phased implementation approaches, forming partnerships with system integrators, and investing in workforce upskilling to build trust and readiness for AI solutions.

By automating manufacturing processes, AI enables industries to align sustainability and profitability, providing a competitive edge in an increasingly dynamic and regulated market. Some innovative startup companies are well-positioned to drive this transformation with tailored solutions that address the unique needs of continuous process industries, paving the way for a more sustainable and efficient manufacturing future.

3 Bibliography

Henry Bristol, Enno de Boer, Dinu de Kroon, Dinu de Kroon, Federico Torti, n.d. Adopting AI in manufacturing at speed and scale | McKinsey [WWW Document]. URL

<https://www.mckinsey.com/capabilities/operations/our-insights/adopting-ai-at-speed-and-scale-the-4ir-push-to-stay-competitive> (accessed 1.17.25).

Mäki-Lohiluoma, E., Säkkinen, N., Palomäki, M., Winberg, O., Ta, H.X., Heikkinen, T., Kiljunen, E., Kauppinen, A., 2021. Use of machine learning in prediction of granule particle size distribution and tablet tensile strength in commercial pharmaceutical manufacturing. *Int. J. Pharm.* 609, 121146. <https://doi.org/10.1016/j.ijpharm.2021.121146>

Marco Taisch, David Romero, 2024. Report 2024 - New Perspectives for the Future of Manufacturing: Outlook 2030 [WWW Document]. World Manuf. Found. URL <https://worldmanufacturing.org/report/report-2024-new-perspectives-for-the-future-of-manufacturing-outlook-2030/> (accessed 1.17.25).

Matthew Finio, Amanda Downie, 2024. How is AI being

used in Manufacturing | IBM [WWW Document]. URL
<https://www.ibm.com/think/topics/ai-in-manufacturing> (accessed 1.17.25).

Niko Siltala*, Helena Leppäkoski, Reijo Hynynen, Markku Penttinen, and Jaakko Passiniemi

Project Implementation Model with Postponed Requirements Definition: Findings from the TeknoHUB Project

Abstract: This article is related to the TeknoHUB project, which aims to enhance the technological, automation, and digitalization capabilities of SMEs in Upper Savo, Finland. The project identified common technology gaps within the group of participating companies and formed interest groups to develop a model for capability renewal. This paper reports on a project implementation model where the definition of project work packages and their contents is postponed to better align with the needs and inputs of the companies. By delaying the decisions on the research topics and their details, to be made in a facilitated collaborative process of the first phase of the project, the model increased the commitment and participation of the companies.

Keywords: collection of industry requirements, postponed definition of project work packages, project model

***Corresponding Author: Niko Siltala:** Tampere University, Finland, E-mail: niko.siltala@tuni.fi

Helena Leppäkoski: Tampere University, Finland, E-mail: helena.leppakoski@tuni.fi

Reijo Hynynen: Savonia AMK, Finland, E-mail: Reijo.Hynynen@savonia.fi

Markku Penttinen: Iisalmen Teollisuuskylä Oy, Finland, E-mail: markku.penttinen@yla-savo.fi

Jaakko Passiniemi: HJP Kehitys Oy, Finland, E-mail: jaakko.passiniemi@hjpp.fi

1 Background

The TeknoHUB project (06/2021..11/2023) was initiated based on the needs of SMEs in the Upper-Savo region in Finland. These companies realized it was necessary to develop their technology, automation, and digitalization capabilities to prepare for future investments and development actions. The companies considered their own ability to advance automation and make investment decisions as limited, which practically slowed down the implementation of development actions or the realization of their results, thereby hindering the growth and renewal of the companies.

To address these needs, the overall goal of the TeknoHUB project was to improve the rapid digital and technological adaptability of supplier companies and SMEs in Ylä-Savo region, improving conditions for significant and rapid growth in response to changing customer demand and operating environments. Additionally, the aim was to encourage SMEs to collaborate with universities to ensure that they have the latest available knowledge to support their technology development efforts. The project also aimed to develop collaborative peer learning among companies by pursuing specific, limited technological targets selected by the companies within the work package participants.

Unlike in typical collaborative development or improvement projects, in TeknoHUB only the upper-level goal for improving digital and technological adaptability was given in the grant decision. However, the actual work package structure and the package contents such as the tasks to be performed were partially left open. The first phase of the project was to collaboratively define the content of the work packages, i.e., to decide the main themes for the development and improvement actions. However, according to the requirements of the funding instrument, the work packages needed to be chosen so that each package served more than just one participating company. On the other hand, to ensure the motivation to participate, for each company, there needed to be at least one work package that addressed the technology and digitalization gaps relevant to the company.

The project was divided into three individual phases: Phase 1) Identify technology and digitalization gaps, form small interest groups around the gaps, and create a model for capability renewal for the next phase. Phase 2) Rapidly improve key technology capabilities through technology transfer, pilots, and demos, and start R&D activities with research institutions. Phase 3) Develop the 'TeknoHUB' model for ongoing collaboration between companies and educational institutions, which can be used to establish new investment and development projects.

In addition to the upper level goal, the types of tasks to be performed in the work packages were partially predefined. In the project funding decision, a significant portion of the funding for the second phase was reserved for the students conducting their thesis research. Their research topics focused on minimizing the technology gaps identified in the first phase and increasing knowledge in the content areas of the project work packages.

The aim of this article is on the first phase and the beginning of the second phase of the TeknoHUB project: feasibility study and needs assessment from participating companies, and definition and prioritization of research topics and technology pilots developed in the technology study phase. The research questions addressed in this article are: **RQ1.** What kind of process can be used to identify the needs of SME companies and produce information that supports those company needs for new technology intake? **RQ2.** What research needs or knowledge gaps do machine shops and similar SME companies have?

2 Materials and Methods

The method we followed to tackle the postponed definition of work packages and their detailed content included the following steps: 1) We first found out the current state and future needs of companies with semi-structured interviews to CEO and other top management. The interview sessions lasted 2..3 hours and were recorded and analyzed later. A factory tour was included to have a look at the facilities, machinery and processes used, the manufactured products, the operations, and the way of work. 2) We formed a technology needs matrix from the interview data and the factory tour observations. Matrix included a list of technologies with topical grouping, our own description of technology, and indices indicating company interest. In the matrix, 42 technologies were listed.

3) The matrix was introduced to the companies and they could refine the results. They prioritized technologies according to their own interests. Each company had a total of 6 points available to distribute over their desired technologies to research. Points could be allocated to 1..6 technologies, giving the company a possibility to weight their choice. In addition, time period for applying technology was asked with three options: 0..1 year, 1..4 year, or later. 4) Based on interest index, company prioritization points, and time spans, we established weighted score for each technology. Based on

score and company prioritizations we re-grouped the table and made proposals for three work package themes out of the topics and companies. Each company had primary and secondary interest groups defined. The outcome was then handed over to the companies for final comments.

5) The companies were divided into three interest groups. Based on the available resources of the companies, they chose one to three interest groups to participate in. The role was either participant or follower, each company having at least one participant role. A coordinator and technical experts from research organizations were nominated for each interest group. The proposal for the technologies to focus on was also made. 6) A workshop was organized to introduce the work packages and agree on the operational models, responsibilities, rules, and reporting. The second half of the workshop was conducted within the interest groups and started the work package activities. 7) The facilitated initial workshops defined the work packages and had three main outcomes: It defined the final theme and aim for each work package, the final set of prioritized key topics, and prioritized the set of key questions the participating companies would like to solve in each topic.

Workshops with companies were associated with steps 2), 4), 6), and 7). The commitment and inclusion of the companies was essential to successfully complete this initial phase of the project. At the same time, it tightly defined the direction and success of the project.

The first phase of the project included steps 1..6 and the second phase started with step 7. After this, each of the work packages started their normal project and research activities. In the TeknoHUB project, it meant actions such as literature review, arranging webinars on core topics with invited experts, benchmarking trips, pilots, and technical demonstrations, BSc and MSc thesis, and collaboration across other research projects.

3 Results

The main result of our paper and the answer to RQ1 is the method used to define the structure and contents of the work package for the technology needs of SME companies. The process and its details will be described in the final paper. In the full paper, we will present the results of the activities and data collected from the definition steps, which will answer the RQ2. The full paper also includes an analysis and discussion of our findings based on the implemented project.

Vjatsheslav Kekshin*, Artjom Kurapov*, Vladimir Kuts*

Integration of Beekeeping with the Concept of Smart Manufacturing

Abstract: Smart manufacturing encompasses various industries, including honey production on beekeeping farms. Modern technologies enable the resolution of complex and critical tasks in this field. This scientific article presents a method for integrating smart manufacturing into beekeeping. It describes the concept of digital control over processes inside hives, automation of hive management processes, monitoring, and problem forecasting. This, in turn, simplifies traditional beekeeping methods and improves both the vitality of bees and the productivity of honey production. Beekeepers of various levels, from amateurs to professionals managing large apiaries, are in great need of technologies that can enhance their efficiency. However, modern mass markets for beekeeping equipment, unfortunately, lack affordable solutions. Therefore, this problem remains relevant and requires attention in this field.

Keywords: Digitalisation, Automation, Smart manufacturing

***Corresponding Author:** Early Stage Researcher. Tallinn University of Technology, School of Engineering, Department of Mechanical and Industrial Engineering, E-mail: vjatsheslav.kekshin@mail.ee

Second Author: Founding engineer, Gratheon OÜ, E-mail: artkurapov@gmail.com

Third Author: Assistant Professor. Tallinn University of Technology, School of Engineering, Department of Mechanical and Industrial Engineering, E-mail: vladimir.kuts@taltech.ee

Introduction

Honey production is a complex and meticulous process that requires a high level of knowledge in this field and involves solving numerous complex tasks, such as: monitoring the condition of the bee colony includes necessary regular (weekly) inspections, fighting varroa mite infestations, predicting swarming, tracking queen presence, controlling colony growth/efficiency, and preventing starvation. The appliance of automated control procedures and targeted interventions against

critical beehive conditions is the beekeeper's main concern and is carried out through periodic control checks of the entire apiary [1]. Human labor becomes more efficient with the use of smart manufacturing in beekeeping. Physical labor is reduced, and with an increase in the number of beehives, human labor does not increase. Additionally, the time for visual inspection and diagnostics of hives on-site is shortened.

Materials and methods

The methodology involves selecting a combination of hardware and software and establishing a connection between automated tasks and the operator.



Figure 1. Data analytics SaaS app for beekeepers

For data analysis in beekeeping, we use a SaaS (Figure 1) application that includes AI detections of frame photos, bee counts, queen and queen cups, varroa mites, frame cells, management of apiaries, hives, frames, and photos, an AI advisor, a mobile app, manual inspections, an inspection timeline, and re-training on user data. Therefore, to accurately analyze the impact of the environment on the state of the bee colony, it is necessary to use sensor devices with sufficient accuracy [2].

IoT sensors for beehives are integrated with hardware for transmitting infrequent telemetry data and are used to measure internal hive temperature. The temperature is a very important parameter for bee colonies, as its detection can be used to identify different conditions in the hive, such as brood development, the pre-swarming condition, and, in general, the health status of the hive [3]. IoT sensors, also are used to measure humidity, atmospheric pressure, hive weight, CO₂ levels inside the hive, PM2 pollution outside the hive, wind speed, and audio. Numerous algorithms can be used for feature extraction and analysis of bees' acoustic [4]. Putting a sensor inside a beehive to gather data from a colony is an advantage over being outside [5].

The web application enables plotting time series data in Grafana, performing analytics through graphs for identifying correlations and anomalies, and generating notifications.

Monitoring the entrance of a beehive is comprehensively performed using the Vision application and an IoT device (Figure 2). It includes video streaming and playback (Figure 3), counting incoming/outgoing bees, varroa mite detection, detecting seizures caused by pesticide exposure, monitoring pollen foraging activity, ant infestations, queen mating flights, theft alerts, and hornet attack notifications.



Figure 2. Hive entrance video monitoring / IoT device



Figure 3. Video streaming & playback

In addition, smart beehives can include a frame extraction mechanism (Figure 4), 2 cameras to take photos of the frame for uploading to a web app, frame extraction for honey harvesting, frame movement across hives, and initially, a robot for a single colony. It moves on rails and also contains sensors for temperature, humidity, weight, and audio monitoring, as well as ventilation, automatic feeding, and anti-varroa mite treatment. The varroa mite disease is one of the most common causes of bee mortality [1].

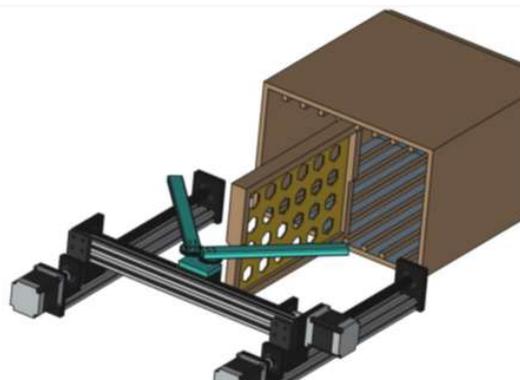


Figure 4. Frame extraction mechanism

Conclusion

In the course of the study, a methodology was developed for the implementation and use of smart manufacturing technologies in beekeeping. The technology, consisting of data collection devices, software, and data transmission peripherals, has proven its suitability and efficiency in use. This enables the simplification of tasks in beekeeping while improving the quality and productivity of honey production.

Bibliography

- [1] Sotirios Kontogiannis. Beehive Smart Detector Device for the Detection of Critical Conditions That Utilize Edge Device Computations and Deep Learning Inferences. 2024
- [2] Yiyao Zheng, Xiaoyan Cao, Shaocong Xu, Shihui Guo, Rencai Huang, Yingjiao Li, Yijie Chen, Liulin Yang, Xiaoyu Cao, Zainura Idrus, Hongting Sun. Intelligent beehive monitoring system based on internet of things and colony state analysis. 2024
- [3] Pier Paolo Danieli , Nicola Francesco Addeo, Filippo Lazzari, Federico Manganello and Fulvia Bovera. Precision Beekeeping Systems: State of the Art, Pros and Cons, and Their Application as Tools for Advancing the Beekeeping Sector. 2024
- [4] Cassandra Uthoff, Masun Nabhan Homs, Martin von Bergen. Acoustic and vibration monitoring of honeybee colonies for beekeeping-relevant aspects of presence of queen bee and swarming. 2023
- [5] Hugo Hadrur, Doreid Ammar, Laurent Lefevre. Toward an intelligent and efficient beehive: A survey of precision beekeeping systems and services. 2022

Petri Hietaharju*, Mika Ruusunen, Jari Ruuska, Jani Tomperi, Pekka Rossi ja Elisangela Heiderscheidt

Kaukolämpö- ja vesihuoltojärjestelmän sektori-integraation mallinnus, simulointi ja optimointi

Tiivistelmä: Paperissa esitetään simulaattori uudentyyppisen kaukolämmön ja vesihuollon sektori-integraation optimointiin, jossa kaukolämmön paluuveden lämpöenergiaa hyödynnetään jäteveden lämmityksessä. Tavoitteena on vähentää kaukolämmöntuotannon polttoaineenkulutusta ja parantaa biologisen jätevedenpuhdistuksen, erityisesti typenpoiston, tehokkuutta. Mallinnuksen, simuloinnin ja optimoinnin avulla tuotetaan uutta tietoa sektori-integraation energiatehokkuus- ja ympäristövaikutuksista sekä optimaalisesta toteutuksesta. Alustavat simulointitulokset osoittavat, että sektori-integraatio mahdollistaa jäteveden lämpötilan ympärivuotisen vakioinnin ja on taloudellisesti kannattavaa kaikille osapuolille.

Asiasanat: sektori-integraatio, kaukolämpö, jätevesi, simulointi, optimointi

***Vastaava kirjoittaja:** Oulun yliopisto, E-mail: petri.hietaharju@oulu.fi

Muut kirjoittajat: Oulun yliopisto, E-mail: mika.ruusunen@oulu.fi, jari.ruuska@oulu.fi, jani.tomperi@oulu.fi, pekka.rossi@oulu.fi, elisangela.heiderscheidt@oulu.fi

1 Tausta

Liika typpi aiheuttaa vesistöjen rehevöitymistä ja happikatoa, joten sen tehokas poistaminen jätevedestä on tärkeää [1]. Poiston tehokkuus riippuu jäteveden lämpötilasta, jonka tulisi olla bakteerien kannalta optimaalinen. Matala jäteveden lämpötila hidastaa puhdistusprosessia, mikä pienentää käsittelykapasiteettia johtaen lisäinvestointeihin. Lämpötila vaikuttaa myös kasvihuonekaasupäästöihin. Jäteveden lämpötila vaihtelee vuoden- ja vuorokaudenajan mukaan sekä viemäriverkoston vuotovesien vuoksi. Talvisin ja lumen sulamisen aikana lämpötila laskee usein alle prosessin optimin ja sen nostaminen kesän tasolle voisi vähentää päästöjä kolmanneksella.

Suomessa typen poisto lisää jätevedenpuhdistamon investointi- ja käyttökustannuksia [1]. Kylmät olosuhteet

ovatkin johtaneet erikoislupiin typenpoiston vaatimusten osalta. Optimoimalla jäteveden lämpötila ja tehoktamalla käsittelyprosessia voitaisiin nykyisellä laitospasiteetilla käsitellä suurempi määrä jätevettä.

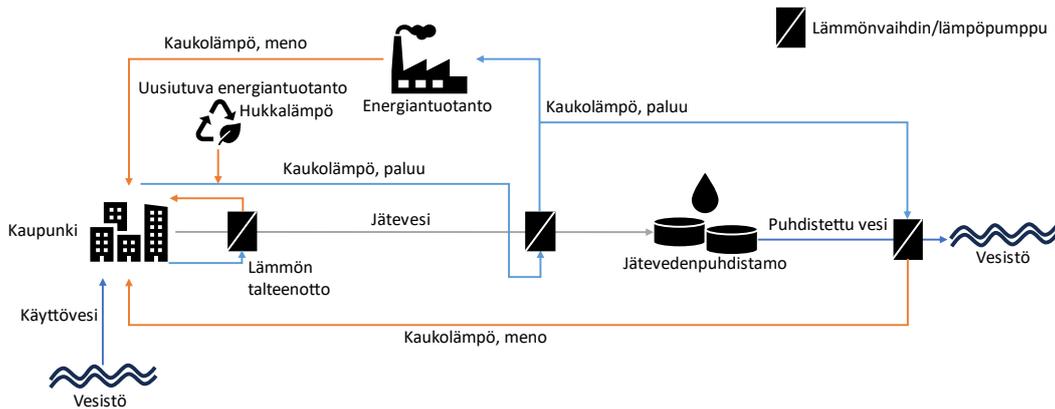
Kaukolämmön paluuvdedessä on lämpöenergiaa, jota voidaan hyödyntää jäteveden lämmitykseen. Paluuvden lämpötilalla on merkittävä vaikutus polttoaineen käyttöön ja päästöihin voimalaitoksissa. Matalampi lämpötila parantaa lämmöntuotannon hyötysuhdetta ja vähentää polttoaineen kulutusta. Paluuvden lämpöenergian hyödyntäminen mahdollistaa myös uusiutuvan energiantuotannon ja hukkalämpöjen lisäämisen jäteveden lämmön talteenoton, mikä alentaa puhdistettavan jäteveden lämpötilaa [1,2]. Kaupungeissa jopa 40 % tuotetusta lämmöstä poistuu jäteveden mukana [3], joten jäteveden lämmöntalteenotto voisi tuottaa kotitalouksissa merkittävän määrän energiaa.

2 Tavoitteet

Tutkimus liittyy KAVENERO hankkeeseen [4], joka keskittyy uudentyyppisen kaukolämpö- ja vesihuoltojärjestelmän sektori-integraation kehittämiseen (Kuva 1) energiatehokkuuden ja ympäristönäkökulmien kannalta. Tavoitteena on vähentää kaukolämmöntuotannon polttoaineenkulutusta ja parantaa biologisen jätevedenpuhdistuksen, erityisesti typen poiston, tehokkuutta hyödyntämällä kaukolämmön paluuvden lämpöenergiaa jäteveden lämmityksessä. Hanke tuottaa simulointimallien avulla uutta tietoa sektori-integraation energiatehokkuus- ja ympäristövaikutuksista sekä optimaalisesta toteutuksesta.

3 Menetelmät

Sektori-integraation vaikutusten arvioiminen on haastavaa ja vaatii eri prosessien yhteisvaikutusten tarkastelua. Paperissa esitettävä optimointisimulaattori on kehitetty sektori-integraation vaikutusten tutkimiseen ja optimaalisen toteutuksen löytämiseen. Optimointi huomioi sekä taloudelliset että ympäristölliset vaikutukset kaukolämpö- että vesihuoltojärjestelmien osalta. Kaukolämpöjärjestelmän osalta simulaattorissa on mukana yhdistetty lämmön ja sähkön tuotanto



Kuva 1. Periaatekuva kaukolämpö- ja vesihuoltojärjestelmän sektori-integraatiosta.

(CHP), lämpökattilat (öljy ja sähkö), lämpöpumput sekä lämpövarastot. Lisäksi huomioidaan mahdolliset hukkalämmöt ja uusiutuvat lämpöenergiat. Energian kysyntäpuolella huomioidaan kiinteistökohtainen jäteveden lämmön talteenotto. Vesihuoltojärjestelmän osalta huomioidaan jäteveden lämpötilan vaikutus typen poiston tehokkuuteen.

CHP- ja lämpölaitokset mallinnetaan huomioiden niiden lämmön- ja sähköntuotannon hyötysuhteet, tehon muutosnopeudet sekä savukaasujen lämmön talteenotto (CHP). Lämpöpumppujen lämpökerroin (COP) perustuu lämpötilaeroon nielun ja lähteen lämpötilojen välillä. Varastointijärjestelmissä huomioidaan lämpöhäviöt sekä purku- ja lataustehokkuudet.

Dynaamista lämmönkulutusmallia käytetään ennustamaan rakennusten lämmönkulutusta. Huomioiden kaukolämpöverkkoon liittyvät lämpöhäviöt ja viiveet, lämmöntuotanto ennustetaan tuntitasolla perustuen ennustettuun lämmönkulutukseen. Energian tuotanto ja varastojen käyttö optimoidaan huomioiden taloudelliset ja ympäristölliset näkökohdat. Optimointiongelma muotoillaan joukoksi lineaarisia rajoitteita ja ratkaistaan käyttäen lineaarista sekalukuoptimointia (MILP).

Optimointisimulaattori on rakennettu modulaariseksi niin, että tutkittavan järjestelmän eri komponentteja, kuten lämmönvaihdin, lämpöpumppu, rakennuskohtainen lämmöntalteenotto, hukkalämmöt ja energiantuotantolaitokset, voidaan lisätä ja poistaa tarvittaessa. Tämä mahdollistaa eri skenaarioiden simuloinnin helposti. Simulointiskenaarioissa jätevesi lämmitetään 16, 20 tai 25 °C lämpötilaan hyödyntäen kaukolämmön paluuvettä. Referenssiskenaariona toimii kaukolämpöjärjestelmän ja jätevedenpuhdistamon nykytilanne. Simulaattori mahdollistaa myös tarkastelun tulevaisuuden tilanteelle, jossa kaukolämmön tuotantorakenne sähköistyy merkittävästi nykyisestä. Modulaarinen ja parametrisoitu toteutus mahdollistaa lisäksi simulaattorin siirrettävyyden ja soveltamisen sektori-integraation tutkimiseen eri kaupungeissa.

4 Tulokset ja johtopäätökset

Alustavat simulointitulokset osoittavat, että sektori-integraatio mahdollistaa jäteveden lämpötilan ympärivuotisen vakioinnin. Tämä parantaa merkittävästi puhdistusprosessin ja typenpoiston tehokkuutta, johtaen taloudellisiin säästöihin. Lisäksi sektori-integraatio on tulosten perusteella taloudellisesti kannattavaa kaikille osapuolille.

Rahoitus

Tämä tutkimus on rahoitettu Euroopan Unionin osarahoittaman EAKR hankkeen Kaukolämpö- ja vesihuoltojärjestelmän energiatehokas sektori-integraatio kaupunkien vihreän siirtymän edistämiseksi (KAVENERO) kautta.

Lähdeluettelo

- [1] Ahonen, M. (2021). Effects of wastewater heat recovery on nitrogen removal in Finnish wastewater treatment plants. Diplomityö. Aalto-yliopisto.
- [2] Laitinen, A., & Wallin, A. (2022). Jäteveden lämmöntalteenoton energiatase kaupungissa. Tutkimusraportti VTT-R-00582-22. Espoo: VTT, 82 s.
- [3] Hepbasli, A., Biyik, E., Ekren, O., Gunerhan, H., & Araz, M. (2014). A key review of wastewater source heat pump (WWSHP) systems. *Energy Convers. Manage.*, 88, 700–722.
- [4] Oulun yliopisto, 2024. KAVENERO – Kaukolämpö- ja vesihuoltojärjestelmän energiatehokas sektori-integraatio kaupunkien vihreän siirtymän edistämiseksi. <https://www oulu.fi/fi/projektit/kavenero-kaukolampo-ja-vesihuoltojarjestelman-energiatehokas-sektori-integraatio-kaupunkien-vihrean>

Micke Talvi* and Kari Lappalainen

Comparison of ramp-rate-based energy storage system control methods for power smoothing of PV systems

Abstract: As the share of highly variable photovoltaic (PV) and wind power production increases, the stability of power grids may be endangered. Issues caused by power fluctuations can be mitigated with ramp rate (RR) limits and energy storage systems (ESS). In this study, 3 different RR-based power smoothing methods for ESSs of PV power plants were compared when the required size and utilization rate of the ESS were considered. This study was based on measured current–voltage curves of a small PV power plant. It was found that even a small modification to the original smoothing method affects the required size and utilization rate of the ESS significantly.

Keywords: energy storage system, photovoltaic power, power fluctuations, power smoothing, control method

***Corresponding Author: Micke Talvi:** Tampere University, E-mail: micke.talvi@tuni.fi

Kari Lappalainen: Tampere University, E-mail: kari.lappalainen@tuni.fi

1 Background and Aims

The share of variable renewable energy sources such as photovoltaic (PV) and wind power is increasing fast in power production. The increasing share of highly fluctuating power production may endanger the stability of power grids. To prevent issues caused by the fluctuating power, multiple countries and regions have set a ramp rate (RR) limit that the grid feed-in powers of power plants must not exceed. For example, Puerto Rico has set an RR limit of 10 %/min [1]. The RR limit is a threshold under which the power fluctuations of the power plants should not cause issues in the power grid. The output power of a power plant can be smoothed to follow the applied RR limit using an energy storage system (ESS). The ESSs can be controlled with different power smoothing methods to achieve the grid feed-in power that follows the applied RR limit. Power smoothing methods that are derived directly from the RR limit are called RR-based power smoothing methods. In [2], an RR-based power smoothing method was introduced and used to study the sizing of the ESSs for PV strings. The power smoothing method used for controlling of the ESS can affect the sizing and

utilization rate of the ESS significantly, as found in [3] and [4], for instance. In [5], the effects of control methods on the sizing of the ESSs was investigated considering the pure RR smoothing, moving average and low-pass filter methods. However, a comparative study considering the effects of different RR-based power smoothing methods on sizing of the ESSs for PV power plants has not been presented.

This paper will study how the use of different RR-based power smoothing methods for the ESSs of PV power plants affects the required size and utilization rate of the ESS. The main objective is to find out which smoothing method would yield the best results when the combination of the size and utilization rate of the ESS is considered. As the PV power fluctuations can be extremely fast, a sampling frequency of 1 Hz or higher would be necessary to detect even the fastest fluctuations, as found in [6]. Thus, this paper will conduct the study with measured PV power that was collected using high enough sampling frequency to give an accurate basis for the study.

2 Materials and Methods

This study is based on measured current–voltage ($I-U$) curves of a PV string of 23 series-connected PV modules of the PV power research plant of Tampere University [6]. The $I-U$ curves were measured during 25 days in May, June, July and August 2023. The measurement period of each day was from 7:00 to 19:00 (UTC+2). The $I-U$ curves were measured once per second. The global maximum power point powers of the $I-U$ curves were used as the generation power of the PV power plant P_{PV} . The nominal power of each PV module was 190 W, and thus, the nominal power of the PV power plant was 4.37 kW. The length and the width of the PV modules were 1475 mm and 986 mm, respectively. The PV modules were facing nearly southward, and the tilt angle of the PV modules was 45°. The applied RR limit was 10 %/min and all the ESSs of this study were virtual. Considering power of the ESS P_{ESS} , positive P_{ESS} corresponded to charging and negative to discharging of the ESS.

This paper compares three different RR-based power smoothing methods for smoothing of the P_{PV} with an

ESS: the pure RR smoothing method (PRR), an RR-based method used in [2], referred to as L2022, and a modified version of the method used in [2], referred to as L2022M. These abbreviations are used also for the corresponding powers and energies of the methods. The PRR method operates the ESS only when a power fluctuation of the power plant exceeds the RR limit – it does not control the energy level of the ESS at all. The L2022 method smooths the power fluctuations to meet the RR limit and controls the energy level of the ESS so that at every moment the ESS would have enough energy for a sudden shutdown of the power plant. In [2], the minimum amount of energy stored in the ESS at every moment was determined by the grid feed-in power P_{grid} , and it can be expressed as

$$E_{ESS, min} = \frac{P_{grid}^2}{2RR_{lim}}, \quad (1)$$

where RR_{lim} is the applied RR limit. With the L2022 method, the energy level of the ESS is also kept as low as possible by discharging the ESS whenever possible. The downside of the L2022 is that it will force the ESS to operate continuously even when the P_{PV} would not fluctuate over the RR limit. Another feature that could be considered as a downside is that the grid feed-in power of the L2022 is significantly smoother than the grid feed-in power of the PRR method. In other words, the L2022 method oversmooths the P_{PV} .

The L2022M method smooths the power fluctuations within the RR limit and also controls the ESS so that it would have enough energy for a sudden shutdown of the power plant. The modification is that the energy level of the ESS is not restricted to stay as minimal as possible. By doing this, the ESS should operate considerably less as it is not discharging energy as often as with the L2022 method. As the ESS is not discharging energy excessively during periods when the P_{PV} is decreasing, the ESS often contains more energy than with the L2022 method. As the ESS has more energy, it will meet the minimum energy requirement of Eq. (1) faster once the P_{PV} starts to increase again. This should yield shorter charging times and smaller charging energies with the ESS.

The ESS sizing quantities were the required charging and discharging power capacities and the required energy capacity of the ESS. The ESS utilization rate was presented as the daily share of energy charged to the ESS, which was calculated as the ratio of the daily energy charged into the ESS to the daily produced energy. The energy level of the ESS was zero at the beginning of each day of the simulation period.

3 Results

The measured PV power fluctuated extremely fast occasionally during the measurement period. The

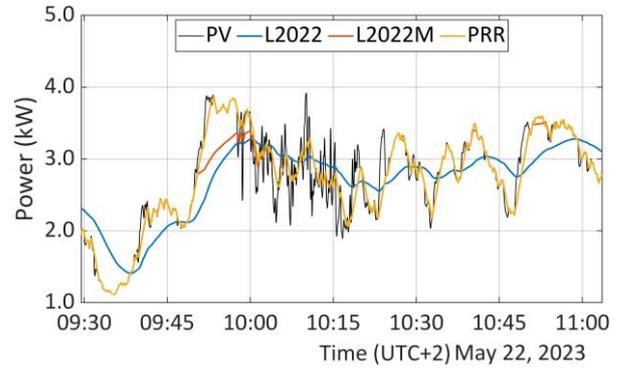


Figure 1. Example of the behavior of the grid feed-in powers of the 3 RR-based power smoothing methods together with the generation power of the PV power plant.

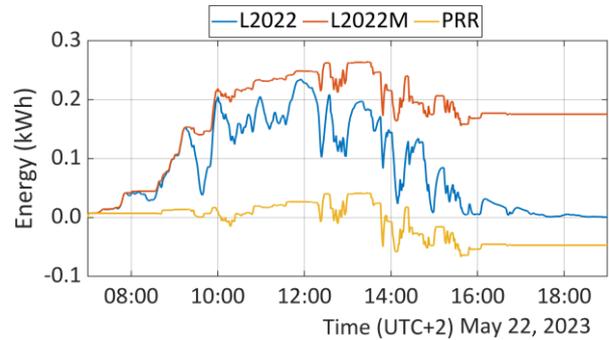


Figure 2. Example of change of the ESS energy level from the initial energy level with the 3 RR-based smoothing methods.

fastest recorded power fluctuations during 1 s were 1314.2 W and 1227.7 W, respectively for the upward and downward power fluctuations. In contrast to the nominal power of the PV power plant, the magnitudes of these power fluctuations were 30.08% and 28.09%. These values are slightly smaller than but still in line with the fastest observed power fluctuations of similar small PV power plants studied in [2] and [7]. Fig. 1 presents an example of the highly fluctuating PV power and the behavior of the grid feed-in powers of the different methods.

Fig. 1 shows that the $P_{grid, PRR}$ followed the P_{PV} closely, as the PRR method only smoothed the fastest fluctuations of the P_{PV} . The $P_{grid, L2022}$ seems to be significantly smoother than the P_{PV} or the $P_{grid, PRR}$. The $P_{grid, L2022M}$ followed the $P_{grid, PRR}$ very closely and was not as smooth as the $P_{grid, L2022}$. The $P_{grid, L2022M}$ was equal to the $P_{grid, PRR}$ most of the time. In general, the $P_{grid, L2022M}$ was differing from the $P_{grid, PRR}$ only when the $P_{grid, L2022M}$ was reaching a new maximum.

Fig. 2 presents an example of change of the ESS energy level from the initial energy level with the 3 RR-based smoothing methods. Fig. 2 shows that $E_{ESS, L2022}$ was constantly changing as the slope of its graph was never 0, in general. Whereas with the other two methods, the

Table I. Required relative charging powers, discharging powers and energy capacities of the ESS, and daily maximum shares of energy charged to the ESS.

Method	L2022	L2022M	PRR
Charging power (%)	75.9	73.3	73.3
Discharging power (%)	67.7	67.1	69.4
Energy capacity (h)	0.0689	0.119	0.173
Energy charged to the ESS (%)	11.2	8.44	7.67

energy level of the ESS remained constant a major share of time. When the energy level of the ESS remained constant, the ESS was not operating. This means that the ESS was operating a significantly larger share of time when the L2022 method was used to control the ESS.

Table I presents the ESS sizing and utilization results for the different methods. The ESS sizing results are presented as values relative to the nominal power of the PV power plant. Table I shows that the relative charging and discharging powers required for the ESS were quite similar among the different methods. The required relative discharging power values of the methods are quite close to the corresponding value of [2] (74.6%), but there is a notable difference between the required relative charging power capacities of this study and the corresponding value of [2] (90.2%).

All the values of the PRR method are smaller than the corresponding values of [5] in which the ESS sizing was done for a simulated 10 kW PV power plant using the PRR method. The difference in the values is caused by the shorter simulation period and the lower sampling frequency of this study. In [5], a sampling frequency of 10 Hz was used, which makes it possible to detect even the fastest PV power fluctuations, as stated in [6]. Hence, the required size for the ESS was larger, and it was utilized more in [5].

The required relative energy capacities differed significantly among the methods. The smallest value was achieved with the L2022 method, and the highest with the PRR method. The value achieved with the L2022 method is in line with the corresponding value of [2] (0.078 h). The significant difference among the values of the methods is reasonable, as the energy level control of the ESS is significantly different among the methods. In fact, the required relative energy capacity of the ESS with the PRR method resulted from a day during which the energy level of the ESS went considerably negative with respect to the initial level.

The L2022 method yielded the highest daily maximum share of energy charged to the ESS among the methods. This was expected, as the L2022 method forces the ESS to operate continuously. The highest daily maximum

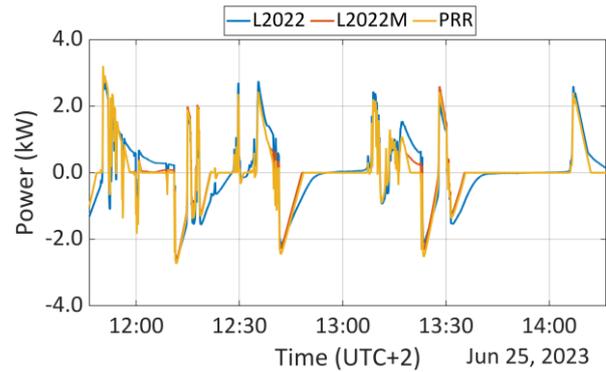


Figure 3. Example of the behavior of the ESS powers of the methods during a day with high power fluctuations.

share of energy charged to the ESS with the L2022 method is significantly smaller than the corresponding value of [2] (17.6%). The PRR method achieved the smallest value for the highest daily maximum share of energy charged to the ESS.

The differences in the ESS utilization among the methods can be seen in Fig. 3 which presents an example of the ESS powers of the methods during the day which yielded the highest daily shares of energy charged to the ESS for the L2022M and the PRR methods. Fig. 3 shows that the $P_{ESS, L2022}$ differed significantly from the other two methods. It can be seen also that the $P_{ESS, L2022}$ was changing continuously even during the periods when the $P_{ESS, L2022M}$ and the $P_{ESS, PRR}$ remained zero. The $P_{ESS, L2022M}$ followed the $P_{ESS, PRR}$ closely most of the time.

The notable differences between the values of this study and [2] regarding the required charging power and the utilization rate of the ESS with the L2022 method, can be explained by the different and longer measurement period that was used in [2] (38 days). The fastest recorded PV power fluctuations during the measurement period of [2] were faster than the ones of this study. Thus, it is reasonable that the measurement period of [2] yielded higher charging power and daily utilization rate for the ESS.

4 Conclusions

It can be concluded that there can be significant differences how different RR-based power smoothing methods affect the sizing and utilization rate of the ESS of a PV power plant. It was found that even a small modification to the original L2022 method lowered utilization rate of the ESS by 25%. But at the same time the required energy capacity for the ESS was increased by 73%. The power requirements for the ESS stayed roughly the same. The energy level control of the ESS seems to have a significant impact on the required energy capacity and the utilization rate of the ESS when RR-based power smoothing methods are considered.

5 Bibliography

- [1] V. Gevorgian and S. Booth, Review of PREPA Technical Requirements for Interconnecting Wind and Solar Generation, National Renewable Energy Laboratory Technical Report, 2013.
- [2] K. Lappalainen and S. Valkealahti, Sizing of energy storage systems for ramp rate control of photovoltaic strings, *Renewable Energy*, vol. 196, pp. 1366–1375, 2022.
- [3] J. Martins, S. Spataru, D. Sera, D.-I. Stroe and A. Lashab, Comparative Study of Ramp-Rate Control Algorithms for PV with Energy Storage Systems, *Energies*, vol. 12, 1342, 2019.
- [4] S. Sukumar, M. Marsadek, K.R. Agileswari and H. Mokhlis, Ramp-rate control smoothing methods to control output power fluctuations from solar photovoltaic (PV) sources—A review, *Journal of Energy Storage*, vol. 20, pp. 218–229, 2018.
- [5] M. Talvi and K. Lappalainen, Effects of Control Strategy on Sizing of Energy Storage Systems for PV–Wind Power Plants, In *Proceedings of the 40th European Photovoltaic Solar Energy Conference*, vol. I, 020538, 2023.
- [6] D. Torres Lobera, A. Mäki, J. Huusari, K. Lappalainen, T. Suntio and S. Valkealahti, Operation of TUT Solar PV Power Station Research Plant under Partial Shading Caused by Snow and Buildings, *International Journal of Photoenergy*, vol. 2013, article ID 837310, 2013.
- [7] K. Lappalainen and S. Valkealahti, Experimental study of the maximum power point characteristics of partially shaded photovoltaic strings, *Applied Energy*, vol. 301, 117436, 2021.

Tomi Peltola*, Tommi Pesu, Janne Lehtinen, and Kalle Raita

Data-driven pallet packing made easy

Abstract: Optimizing pallet packing decreases the resource use and cost of transporting goods. A classical optimization approach is bin packing. It assumes knowledge of item dimensions, is computationally demanding, and has many practical complications. We introduce an alternative approach that relies only on historical data of packed pallets and item identities. For a new order to be packed, the method first produces pallet templates from the data. Given the templates, a discrete optimization problem is solved to find the optimal item-to-pallet assignments. In addition, we designed a web-based user interface for logistics experts to examine and fine-tune the result. The user interaction is captured in the background to enrich the pallet template data, teaching the method better solutions. The application is deployed at a furniture maker, integrated into their enterprise resource planning software. Its maintenance is easy.

Keywords: logistics, pallet packing, bin packing

***Corresponding Author: Tomi Peltola:** Digisalix, E-mail: tomi.peltola@digisalix.fi

Tommi Pesu: Digisalix, E-mail: tommi.pesu@digisalix.fi

Janne Lehtinen: Digisalix, E-mail: janne.lehtinen@digisalix.fi

Kalle Raita: Digisalix, E-mail: kalle.raita@digisalix.fi

1 Background

Transportation of large shipments of goods is resource-intensive and costly. Optimizing packing of the items can help reduce the impact on the environment and the cost for the customer. Our motivating case is packing large orders of furniture on pallets at the factory for shipment to new or newly-furnished buildings. Manually planning the assignment of ordered items onto pallets requires slow-to-learn expertise and is burdensome. In addition to guiding packing, the automation also helps customer service to estimate shipment costs faster.

A classical mathematical optimization approach is *bin packing*. It assumes knowledge of the item packing dimensions and is computationally demanding. Further complications arise, for example, from irregularly shaped items, item stacking restrictions, or items requiring scaffolding for safe transportation.

We introduce a data-driven approach that only needs historical data on packed pallets and item identities

(e.g., product codes) and does not rely on item dimensions. Such data is often readily available from enterprise resource planning software or similar source and is automatically kept up-to-date as part of packing new shipments. The advantages of the approach are:

- Interpretable and intuitive for logistics experts: The source data is in the form of historical packed pallets, familiar to the expert. The optimization result can be easily traced back to the source data.
- Instantly adaptable: The expert can modify the dataset, making the method produce better solutions. The improvement workflow can be automated in the background of natural user operation.
- Easy deployment and maintenance: Simple, readily-available source dataset. No costly and brittle re-training like in most machine learning methods¹. The dataset improves naturally as part of operating the software and with more shipped deliveries.
- Validity of solutions: the solutions are always packable as long as the pallets in the dataset are.
- No need for special hardware such as graphical processing units.

2 Data-driven pallet packing

Our aim is to minimize the resource use or cost of assigning a given list of items (*current order*) to pallets (or other packages; for concreteness, we speak of pallets). The method is based on historical data of packed pallets: for each packed pallet in the data, we only require the identities and counts of the items.

The method then works in two steps:

1. Extract *maximal pallet templates* from the data containing items in the current order.
2. Using the templates, formulate and solve an *integer-programming problem* to minimize the cost of assigning the items to pallets.

In step 1, a *pallet template* is a set of items and their counts that can be packed to a single pallet. A *maximal pallet template* is a template that is a strict superset of any other pallet in the data with respect to the items in the order. As an example, consider items

¹ The approach can be seen as a non-parametric machine learning method in the vein of *k*-nearest neighbor classifier.

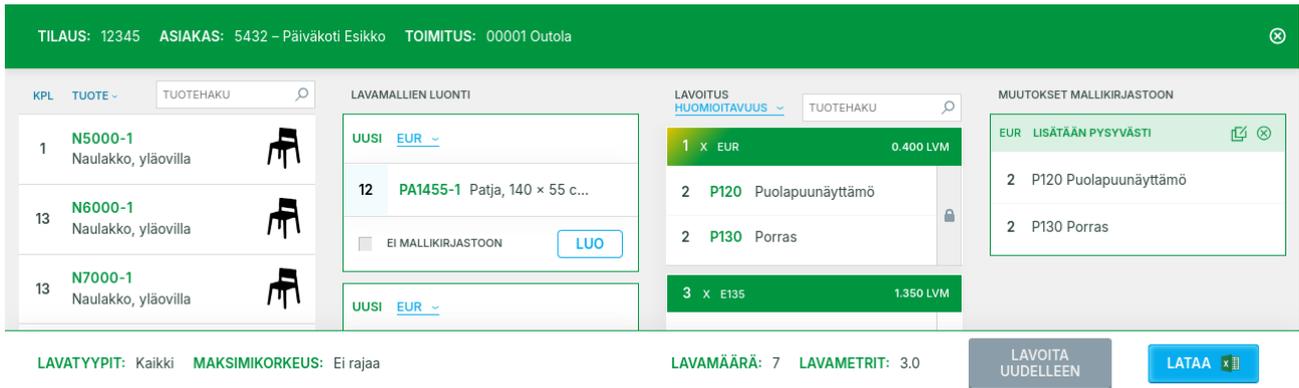


Fig. 1. Screenshot of the web-based user interface (texts in Finnish). The header shows order meta data. The footer shows pallet constraints and output information. The main window has four columns: (1) listing of ordered items, (2) pallet template editor allowing creating new pallet suggestions, (3) current pallet packing solution, and (4) changes to the pallet templates.

A , B , and C , A and B of which are in the current order. Then, the template $(A, 2), (B, 3)$ is better than $(A, 1), (B, 3), (C, 4)$ since it can pack two items A while the latter only one (C is irrelevant because it's not in the order).

In step 2, an *integer-programming problem* is formulated to assign all of the order items to pallets. The use counts of the extracted set of templates form the space of candidate solutions, with constraints requiring all items to be assigned to a pallet. In the simplest case, the cost of a solution is the number of used pallets. Off-the-shelf discrete optimization software packages can be used to solve the problem².

The method can accommodate multiple extensions:

- Different types of pallets: If the history data includes packed pallets with different sizes, the optimization in step 2 can minimize the total transport size (loading meters). Restrictions for pallet types can be enforced by filtering the data in step 1. Similar filtering can be used for shipment height if the data contains heights of packed pallets.
- Item categories: Product codes might identify items too strictly. For example, products differing only in color can be packed exchangeably. Product categories can be then used as item identities.

A strong advantage of the method is that the source data, the packed pallets, is very intuitive for a logistics expert. As such, if the method suggests an over-filled pallet, the source template can be identified and removed from the data. If the expert recognizes more efficient packing solutions, new templates can be added

² CP-SAT solver in Google OR-Tools, Python package version 9.7.2996, <https://developers.google.com/optimization>.

to the dataset, making the algorithm learn better solutions. The method adapts instantly without re-training.

A disadvantage is that the method doesn't extrapolate outside of the template data. This makes it conservative in the sense that the solutions are valid (can be packed as long as all pallets in the data are valid). This, however, can give suboptimal solutions when not-yet-seen combinations of items could be used to pack more efficiently. Moreover, new products cannot be efficiently packed (unless they can be categorized together with an existing product). Machine learning based prediction could be used to alleviate the issues, for example, by predicting new templates or item size correspondences.

The optimization algorithm also doesn't inherently distinguish between solutions with the same cost. Logistics experts, however, might prefer certain solutions to others, for example, because of ease of packing or unpacking. Such preferences don't often explicitly exist in the recorded data, but might be reflected in the distribution of packed pallets. If available, the preferences could be directly used in the optimization cost. Otherwise, statistics or machine learning could estimate them from data and, for example, re-rank equivalent solutions. A good user interface can also alleviate the problem.

3 User interface

Figure 1 shows the web-based user interface. The changes of the user to the optimization result are recorded in the back-end to improve the template data. The application is deployed at a furniture maker, integrated into their enterprise resource planning software.

Iiro Jantunen*

Cybersecurity Considerations of Industrial Automation Supply Chain

Abstract: The assessment of reliability of industrial automation hardware and software suppliers is commonplace. The September 2024 attacks on pagers and walkie-talkies in the Middle East, however, cast a shadow over the devices of reliable suppliers, also. The possibility of someone in the supply chain hiding harmful components or software in automation devices and systems requires thorough consideration. The EU cybersecurity directive (NIS2) and similar regulations also put demands for industrial entities to manage their supply chain risks.

It is advisable for the purchaser of industrial automation to address the cybersecurity of the ordered system and its supply chain already at the request for proposal stage, just as with other technical requirements. Industry standards and guidelines help. A clear table of requirements facilitates the project by providing both the customer and the supplier with a consistent picture of the desired outcome. If cybersecurity requirements are only raised during the project, the risks are additional costs for extra work as well as superficial security.

Installation, maintenance, and servicing, including software updates, are also important parts of the supply chain from the security perspective. This applies to both on-site service personnel and transport of the devices for external maintenance.

Keywords: cybersecurity, ICT/OT, supply chain, maintenance, automation hardware, automation software, device tampering, computer viruses

***Corresponding Author:** Iiro Jantunen, Rejlers, E-mail: iiro.jantunen@rejlers.fi

1 Introduction

The September 2024 attacks [1] made visible the risk inherent in purchasing automation systems and components. Even the devices provided by reliable manufacturers can be tampered within the supply chain. An explosive is by no means necessary to cause damage: it is enough to disrupt the operation of an industrial plant with e.g. software, such as the Stuxnet virus [2]. The failure (or destruction) of industrial machinery or process equipment may also cause wider

damage to the facility, the personnel, and the environment. Cybersecurity thus affects also the safety of automation systems [3]. The automation supply chain contains vulnerabilities at all stages from component suppliers to maintenance [4]. If an outsider in the supply chain gains access to the device, it can be tampered. If this outsider has the resources of a state intelligence service, the device and its packaging could probably be modified so that no changes in the supply chain are detected at a later stage. This also applies to software.

2 Standards and regulations

Certified compliance with technical standards such as the IEC 62443 family (OT) and the ISO/IEC 27000 family (ICT) as well as requirements set by the EU 2024/2847 Cyber Resilience Act (CRA) to CE markings, guarantee to a certain extent that the original manufacturer of the device has made the device secure. A supply chain still has its inherent vulnerabilities.

In Europe, the issue has been proactively addressed: the EU Cybersecurity Directive (NIS2), which came into force in October 2024, requires companies and other actors to ensure supply chain security, including security-related aspects concerning the relationships between each entity and its direct suppliers or service providers [5]. The implementing regulation EU 2024/2690 specifies requirements for supply chain security [6]. These requirements should be thoroughly understood by the companies that purchase automation equipment and systems.

Guidelines for the monitoring of supply chains can also be found in public sources such as *Cybersecurity Supply Chain Risk Management Practices for Systems and Organizations* (NIST). This publication advises to obtain components either directly from the manufacturer, an authorized distributor or an authorized reseller, in that order [7]. Purchasing organizations should verify the authorization of a distributor or reseller. Proper due diligence of suppliers should be performed, and the prime contractors should require similar control and requirements from relevant sub-tier contractors [8]. Also procured engineering services should be regularly evaluated from a security point-of-view.

It is worth noting that the supply chain does not only refer to equipment, but also to software as well as services. Extensive studies of system and component vulnerabilities (OT:ICEFALL [9] and INFRA:HALT [10]) have found that OT components often use poorly maintained software components, such as runtime systems and TCP/IP software.

The case of CrowdStrike Falcon software update in July 2024, as well as other similar incidents, emphasizes the risks of poorly managed software updates [11]. Timely execution of cybersecurity-related updates is crucial, but the balance between testing and speed must be set carefully. Cyber resiliency analysis of systems is needed, considering all relevant attack types. This is especially important in industrial system environments. Should a malicious party be able to insert their code into a software update, they would be able to hit several industries with a single strike.

Maintenance and servicing are also important parts of the supply chain from a security perspective as they can compromise system integrity. This applies to on-site service personnel, remote software maintenance and reconfiguration, and transportation to external maintenance. In the latter case, the security of logistics services should also be considered. Note the EU NIS2 requirement of human resources security and access control policies [12, 13]. Any trespassing of locked area containing network or automation systems can compromise system integrity (the case of break-ins in water services around Finland as an example [14]).

For all this, one needs a comprehensive asset management system to keep track of all the devices and software, as well as their dependencies, included in one's ICT/OT systems [15, 16].

3 Conclusions

Companies must understand their risk profile and adjust the measures they use accordingly. A cyberattack by a foreign state is more likely to happen in sectors critical to society (such as the essential and important entities defined by EU NIS2 [17]) than in less critical sectors. On the other hand, the risk posed by criminal actors depends more on the potential of financial damage and thus, inversely, gain.

The purchaser of industrial automation should address the cybersecurity of the ordered system and its supply chain already at the request for proposal stage, just like other technical requirements. A clear table of requirements included with the request for proposal for the supplier to fill out facilitates the project in advance by providing both the purchaser and the supplier with as consistent a picture as possible of what is desired as the outcome. Aforementioned standards and guidelines help in writing the requirements. If

cybersecurity requirements are raised only during the project, the risk is low superficial security as well as additional costs for extra work.

Even the best cybersecurity practices can be thwarted by the human factor. Policies must therefore be taught to all relevant people. However, people are prone to mistakes, especially when they are stressed or in a hurry — just when they should be at their most careful. If cyber-secure operations are made difficult and laborious, the temptation for an easy shortcut is great.

4 Bibliography

1. R. Berg, Ex-Israeli agents reveal how pager attacks were carried out, BBC, 23.12.2024
2. D. Sanger, Obama Order Sped Up Wave of Cyberattacks Against Iran, The New York Times, 1.6.2012.
3. T. Malm, R. Tiusanen, J. Berger, Comparing cybersecurity and functional safety risk assessments, in Proc. SIAS 2024.
4. J. Simola, A. Takala, R. Lehtonen, T. Frantti, R. Savola, The Importance of Cybersecurity Governance Model in Operational Technology Environments, in Proc. 23 ECCWS 2024.
5. EU Directive 2022/2555, ch. IV, art. 21.2.d & 21.2.e, 14.12.2022.
6. EU 2024/2690, Annex I, ch. 5, 17.10.2024.
7. J. Boyens, A. Smith, N. Bartol, K. Winkler, A. Holbrook, M. Fallon, Cybersecurity Supply Chain Risk Management Practices for Systems and Organizations, NIST SP 800-161r1, 2022, p. 141.
8. Ibid. p. 151.
9. OT:ICEFALL — The legacy of “insecure by design” and its implications for certifications and risk management, Vedere Labs, 2022.
10. INFRA:HALT — Jointly discovering and mitigating large-scale OT vulnerabilities, Forescout Research Labs & JFrog Security Research, 2021.
11. R. Yahalom, What the 2024 CrowdStrike Glitch Can Teach Us About Cyber Risk, Harvard Business Review, 10.1.2025.
12. EU Directive 2022/2555, ch. IV, art. 21.2.i, 14.12.2022.
13. EU 2024/2690, Annex I, ch. 10, 17.10.2024.
14. J. Mäntysalo, Murtautumiset kriittisiin kohteisiin herättivät kesällä pelkoa Suomessa — tämä niiden tutkinnasta tiedetään nyt, YLE, 20.1.2025.
15. EU 2024/2690, Annex I, ch. 12, 17.10.2024.
16. EU 2024/2847, Annex I, pts. II.1 & II.6, 23.10.2024.
17. EU Directive 2022/2555, ch. I, art. 3, 14.12.2022.

Juho Pirttilahti, Sakari Pollari, Janne Kapela

Safety system delay measurement and implementation to VR- simulation

Abstract

This paper examines the distinctions between virtual and real-world environments in the assessment of machine safety applications. The high-speed camera was employed for the actual configuration for measurement of single DC motor stop time, which represents part of the real machine architecture. The delay between the activation of the safety laser scanner to the cessation of the motor was measured. Additionally, the delay from the safety laser scanner to the contactor shut down operation was measured. The result serves to establish a benchmark for comparison with a virtual model developed in Unity.

The virtual environment is constructed in such a way as to replicate the real-world system, with the objective of implementing real-world measured delay and safety performance under controlled conditions. By simulating different scenarios, researchers can assess the system's response and identify critical weaknesses without the inherent risks associated with physical machinery.

Latency is a critical factor in the context of safety. It is defined as the time interval between the triggering of a safety condition and the corresponding system action. The reduction of latency is of paramount importance for the implementation of effective safety responses. In the virtual setup, computational latency is analyzed in conjunction with real-world mechanical delays to ascertain the viability of utilizing virtual simulations for safety-critical assessments.

Moreover, the study assesses compliance with ISO 13849, a foundational safety standard that delineates the specifications for control system design. Verification of adherence to these criteria in both the virtual and physical setups serves to validate the robustness of simulations for machine safety systems. The integration of high-speed camera data improves the accuracy of the virtual model, enabling a comprehensive analysis of system behavior under dynamic conditions.

Methodology

To replicate key aspects of the actual machine architecture, a real-world experimental setup was constructed. Delay measurements were performed using a Citius Imaging C100 high-speed camera in conjunction with Citius Imaging 1.48 software, which captured images at intervals of 2.306 milliseconds. The safety laser scanner (Sick nanoScan3), configured with a 20 mm finger detection resolution, was mounted vertically on an aluminum profile bar and aligned with the camera to ensure reliable observation of the safety field activation. The camera's field of view also encompassed a small DC motor equipped with a mechanical rotation indicator and signal lights. These lights indicated the activation of the safety relay (Pilz PNOZ s4) and the switching of the contactor. For the experiment, an operator's hand was employed to trigger the safety light curtain, and the subsequent video recordings were analyzed—using the known frame rate—to calculate the delay from safety field activation to motor cessation.

After the real-world measurements, a virtual reality (VR) model of the test setup machine and its safety control system was developed in Unity. This VR model replicated the stopping architecture of the physical system, with delays for each component (safety light curtain, safety relay, contactor, and motor) parameterized based on the high-speed camera data. The Unity object code was modified to incorporate the motor's ramp-down time, and parameters encompassed an error margin ranging from 1 millisecond to 1 second. This was included in the test using a random generator to emulate the similar standard deviation effect observed in real-world tests.

Results and Discussion

The high-speed camera system was employed to conduct two distinct measurement configurations. In the first measurement, the delay from the activation of the safety scanner to the cessation of the motor was evaluated. This test was repeated ten times, yielding a mean delay of 1404.79 ms with a standard deviation of

50.12 ms.

In the second configuration, indicator lights were incorporated into the circuit following the safety relay and motor contactor. These lights visually indicated the activation of the respective components, which were captured by the high-speed camera. The results from this setup revealed a mean delay of 14.87 ms with a standard deviation of 16.08 ms for the time between the activation of the safety sensor and the triggering of the safety relay. Additionally, the mean delay from safety scanner activation to the state change of the contactor was found to be 26.20 ms, with a standard deviation of 16.63 ms. The total delay from the activation of the safety laser scanner to the cessation of the motor in this second setup was 1388.74 ms, with a standard deviation of 66.68 ms. When combining the results from all 20 trials, the total mean delay from the activation of the safety scanner to the cessation of the motor was 1396.77 ms, with an overall standard deviation of 61.10 ms.

The largest portion of the delay arises from mechanical deceleration of the motor rather than from the electronic or sensing components. The brief intervals measured between the scanner activation and the safety relay (~15 ms) or contactor off (~26 ms) are minimal in comparison. This is consistent with typical small motor inertia and the absence of an electronic brake in the test setup.

The short delays (e.g., scanner-to-relay or scanner-to-contactor) exhibit relatively higher standard deviations (on the order of 16 ms) compared to their mean values. This likely reflects the frame-based measurement resolution of the high-speed camera and potential jitter in signal switching. While the camera provides accurate timing over the full 1.40 s window, sub-30 ms intervals are proportionally more affected by each frame's ~2.36 ms increment.

Conclusions

The experimental results indicate that the high-speed camera reliably detected the laser light emitted by the safety scanner, thereby facilitating precise alignment during testing. However, further investigation is required to refine the accuracy of event timestamp extraction from the video frames, as the software-based frame measurements exhibit a non-negligible tolerance.

In developing the virtual reality (VR) model, it was essential to parameterize two key factors: the nominal delay associated with each component and the additional delay introduced by measurement

tolerance. This approach enables simulation of safety responses under various conditions, providing a robust framework for analyzing system behavior. Moreover, the VR environment allows for rapid testing and optimization of safety measures without the inherent risks and costs of physical trials.

The high-speed camera proved to be an effective tool for validating total delay times—from safety scanner activation to motor cessation—under conditions where safety tolerance is critical. Nonetheless, its precision diminishes when capturing very short time intervals, such as those between the activation of the safety scanner and subsequent events like safety relay or contactor switching. Furthermore, while manufacturers typically provide component reaction times and delay values that incorporate built-in safety factors for practical applications, additional optimization may be necessary to reflect the dynamic performance of the system more accurately under test. However, based on the test, it is more feasible to inspect the stopping time of mechanical systems rather than electrical control systems in simple automation cases.

Keywords: delay, stopping time measurement, virtual reality, safety validation, digital twin

Pirttilahti, Juho: Seinäjoki University of Applied Sciences, juho.pirttilahti@seamk.fi

Pollari, Sakari: Seinäjoki University of Applied Sciences, sakari.pollari@seamk.fi

Kapela, Janne: Seinäjoki University of Applied Sciences, janne.kapela@seamk.fi

Raimo Rahkonen

Engineering a digitalized plant

Abstract: Modern industrial plants rely heavily on numerous software and firmware applications for their operational systems. However, engineering activities are often distributed among various suppliers and other parties without clear implementation requirements or context.

This document discusses of how design engineering and task coordination should be structured to enable plant owners and stakeholders to effectively manage the information about applications and the data they generate. This approach ensures compliance with cybersecurity asset documentation requirements and aligns with European NIS2 [1] and CRA [2] directives.

Keywords: plant engineering, applications context, CRA, NIS2, cyber physical systems, CVEs, CSAF, AI

***Corresponding Author: Raimo Rahkonen,** E-mail: raimo.rahkonen@remuscon.fi

1 Background

In the digital plants managing numerous software and firmware applications is crucial. Two key European directives, NIS2 (Directive (EU) 2022/2555, for a high common level of cybersecurity) and CRA (Cyber Resilience Act), address digitalization and cyber assets management. Proper organization of applications within the plant context is essential for effective risk assessment and management.

This document outlines how to structure applications engineering to empower plant owners and stakeholders. By creating a comprehensive cyber model of the plant, the owner and other stakeholders can sustainably leverage Artificial Intelligence (AI) and related advanced algorithms, to efficiently handle issues related to plant documentation and compliance.

2 Methods

To ensure successful outcomes for various engineering personnel, a systematic and easily understood method is essential. The following chapters outline the key aspects of this approach.

Physical Assets structure

A digital plant consists of several cyber physical systems which may contain other systems [3]. The physical assets are typically organized into an asset tree. In the tree the assets are shown as parents and children, indicating where they belong to in the plant functional structure.

As part of cyber engineering, some physical and functional characteristics may be recorded for information enrichment. Such information contains the purpose of the asset and generic or detailed function. Additional information may be included, especially if the cyber engineering system is not connected to physical engineering. Physical engineering typically provides information on 3D models, mechanical structures' physical connectivity, fluid flows, and power and data networking.

Application requirements

A good practice of defining the functionality of the controls with industrial control systems has been implemented for decades. Functional descriptions or control narratives are useful in providing clear and consistent description of the control logic and operational procedures, to be achieved with the software.

With the software and firmware distributed from field devices, OT systems to cloud instances, it has become necessary to extend this practice to concern all applications, wherever they are executed. In this document we call them application requirements.

The computing platforms where the applications shall be run can be:

- embedded into the asset (sensors, actuators,

- liIoT equipment etc.) itself,
- a drive for an electrical motor, lighting fixture, electrical power distribution IED
- PLC or ICS controller, building automation controller
- platform in virtual environment at the
 - edge,
 - at plant level or
 - cloud

The application requirements are connected to the exact asset (at any level of the asset tree) which the required application shall serve. This method is useful to contextualize the data provided by the actual implemented application. It is also useful to know the context in case of known or foreseen vulnerability to define the risk it may cause.

Implemented Applications

Applications to be run in systems of any plant are effectively composed by manufacturers with methods including previous versions of the same, and relating applications and open-source components. A list of SW components is typically given as Software Bill of Material (SBOM) [4].

The implemented applications themselves are based on selected typical solutions, called for the assets as required by the application requirements. The typical solutions are further developed for the exact asset of the plant, or to a computing platform of a plant system.

It is essential to record the exact version of the typical application to trace the possible bugs and vulnerabilities, CVEs [5] (Common Vulnerabilities and Exposures). There are public sources where known vulnerabilities are published. Some are by governmental authorities and researchers, some by private specialist vendors and applications and systems providers.

A further development to enable a plant owner to disclose information about CVEs are the security advisories.

The security advisories contain not only information about vulnerability, but also advise what to do if you happen to have the application concerned. Some suppliers provide advisories in a machine-readable format according to Common Security Advisory Framework [6] (CSAF). These facilitate automation and reduce the time required to understand impact to plant applications and drive timely remediation.

By creating an inventory database of applications as

given in this document, and using the CSAF advisories, companies can maintain overview and secure the plant systems in an efficient manner.

Summary

Engineering the cyber part of a cyber physical plant as part of the implementation engineering gives the plant owner several advantages compared to finding out the cyber part afterwards.

Allowing plant engineering designers, suppliers and OEM manufacturers to work collaboratively within the plant context with their knowledge on cyber physical systems gives better results both technically and financially.

Additionally, developing contextual information of applications and data enhances the effectiveness of Artificial Intelligence (AI) in case the plant owner decides to use such advanced tools.

3 Bibliography

Attached sources of information cited in the text.

- [1] NIS2 directive: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022L2555>
- [2] Cyber Resilience Act (CRA): <https://digital-strategy.ec.europa.eu/en/policies/cyber-resilience-act>
- [3] Framework for Cyber-Physical Systems: Volume 2, Working Group Reports <https://doi.org/10.6028/NIST.SP.1500-202>
- [4] Software Bill of Materials (CISA): [Software Bill of Materials \(SBOM\) | CISA](#)
- [5] Overview of CVE program: [Overview | CVE](#)
- [6] Common Security Advisory Framework (by BSI): [BSI - Common Security Advisory Framework \(CSAF\)](#)

Automaatiopäivät 2025

Aihealue: Energiaan ja rakennusautomaation liittyvät ratkaisut

Case: Loval, hukkalämmöntalteenotto ja hiilijalanjäljen pienentäminen

Sanni Siltala, Sweco Finland Oy
Ralf Carlsson, Sweco Finland Oy

Loval Oy:n tehtaassa tarvittiin tuotantotiloihin jäähdytystä, joten energiayhtiö Loviisan Lämpö rakennutti tehtaaseen lämpöpumpun. Rakennetulla lämpöpumppulaitteistolla saadaan tiloista hukkalämpö talteen ja tehtaaseen riittävä jäähdytysenergia.

Lämpöpumpulla tuotetaan lämmitystä ja jäähdytystä yhtä aikaa (TER). Loviisan lämpö myy kylmän tehtaalle ja tehtaan hukkalämmöstä tehdyn lämmön kaukolämpöverkkoon.

Hukkalämmön lämpötila saadaan lämpöpumpun avulla nostettua riittävän lämpimäksi Loviisan Lämmön kaukolämpöverkkoon. Tehtaan hiilijalanjälki pienenee, koska lämpöpumpuilla tehty kaukolämpö myydään kolmannelle osapuolelle.

Tuotetun lämmön ja kylmän osuus mitataan ja raportoidaan rakennusautomaatiojärjestelmään, jolloin saadaan tieto hiilijalan jäljen pienentymisestä. Hukkalämmöntalteenotto pienentää Loviisan Lämmön polttoaineenkulutusta, jolloin heidän CO₂-päästöt pienenevät selvästi. Hukkalämmöllä saadaan katettua Loviisan lämmön tuotannosta 30-40%.

Loval Oy:n toive parantaa tilojen lämpötila olosuhteita parantaa tehtaan viihtyvyyttä ja tehtaan tuottavuutta koska taukojen määrät vähenevät kun työskentely olosuhteet eivät niitä enää vaadi.

Rakennusautomaatiolla ohjataan lämpöpumppuverkostojen toimintaa, käytetäänkö hukkalämpöä lämmön tuottamiseen verkostoon, varastoon säiliöihin vai kylmän tuottoon. Kun tarvitaan kaukolämpöä mutta ei ole jäähdytystarvetta, säilötään kylmä tankkeihin. Ja päinvastoin säilötään lämpö tankkeihin, kun on jäähdytystarvetta mutta ei lämmityksen käyttöä. Lämmön huippuja voidaan katkoa varastoidulla lämmöllä.

Rakennusautomaatiolla on suuri merkitys lämmön ja jäähdytyksen optimaalisessa ohjauksessa. Rakennusautomaatioon liitettyjen energiamittarien avulla voidaan seurata järjestelmän toimintaa ja todentaa hiilijalan jäljen pienentymistä.

Heikki Saha*, Tampere University

An improved IoT GW and configuration approach for mobile mining machine applications

Abstract: Typical IoT systems have been based on dedicated sensor networks. Gateways have been designed to route to server the entire communication message by message, without any processing. Further, automatic discovery of sensors has often been used. Data buffering has been used to cope with temporary communication failures only. Modern mining equipment contain electronic control systems, which provide various kinds of data for monitoring. In each site there may be numerous kinds of equipment, each providing different data as different sets. Especially in underground mines, there are areas without any communication network available due to a harsh conditions. This paper presents a new GW concept, which has intentionally been designed to provide a flexible connectivity to various equipment, networks and servers. Intentionally selected data will be extracted into a source independent format. Data buffered by the GW may be sent to the remote server, when a connection exists. Configurability requires well defined management processes to result reliable operation. This paper presents process examples for three major alternative connections, J1939 fleet management, CAN-based superstructure network and a CANopen sensor network. Field tests proved, that the presented GW concept reached the defined targets. The presented configuration processes improved getting the GWs configured without errors.

Keywords: IoT, IIoT, gateway, configuration, mining

***Corresponding Author: Heikki Saha:** Dr., E-mail: heikki.k.saha@tuni.fi

1 Background

A set of physical objects – “things” – that send data and communicate with a network was called first time as a term of the Internet of Things (IoT) in 1999 by the MIT [1]. Industrial IoT (IIoT) may be defined integration of internal and external data, which means typically collecting process data from the actual control system and supplemental extra sensors and combing the data in the server [2] [3]. Different requirements apply to IoT

and IIoT by means of environmental protection and interfacing [2]. Modern distributed control systems use embedded networks, “fieldbuses” for sharing the control system internal data inside the systems [4]. Similar networks are also in use in mobile assets, but may be called differently, e.g. “automotive networks” [5]. Typical use cases for IIoT data include production process, asset usage and service monitoring and optimization as well as invoicing [2] [4] [6].

Mining operations consist of multiple tasks – drilling, charging, exploding, secondary breaking, scaling, loading, hauling and reinforcing following each other and dedicated equipment are required in each task [7]. Typically such means the use of different kinds of equipment from multiple vendors, which leads into further challenges regarding fleet wide production process and condition monitoring systems.

Modern equipment contain distributed electronic onboard control system, e.g. trucks [5], with a standardized network interface for fleet management [8], which is a typical interface to obtain various kinds of remote monitoring data. In addition to the mandatory FMS (fleet management system) data, equipment vendors may provide optional data [9] as vendor specific sets. Some truck vendors provide similar communication also by so called BBM (body builder module) interface, which is intended for superstructure integration. Additionally, there may be one or more control networks dedicated for superstructure, which may need to be connected. Reliable installation of supplemental sensors has been found to be challenging [2].

Depending on mining method, production areas may vary and be in use for short periods. Thus it does not make any sense to build communication infrastructure covering the entire production areas [7]. There is typically an excellent infrastructure in the fixed areas of the mine, in which the data may be sent to the network. The networks available in the mines are company specific, from which a managed Internet connection is available through firewall. The networks contain

business critical data, why communication is strictly constrained due to security and privacy reasons. Thus, the companies prefer to keep the server's master database strictly under their own control. As a result, each company may use different server framework and further use different application programming interface (API) for interfacing.

In underground mines, cellular networks are typically provided in very limited areas such as service areas, offices and lounges. Main underground communication medium is a WiFi. Cellular networks exist underground, but are more widely used for IIoT in surface mines. However, there may exist random blind spots.

Direct internet connection of an individual sensor is difficult to implemented in a proper way, especially with constrained resources [10]. A gateway (GW) is a device integrating sensors with heterogenous interfaces to a cloud platform over an available network connection [11] [4] [12]. In addition to the data routing, a GW may filter, preprocess and buffer the data [13] [12]. Due to the central role of the GW and its configuration in the IIoT systems, GW behavior and related configuration management are in the main scope of this paper.

2 Aims

To develop and evaluate a new IIoT GW concept with characteristics: Smart and passive kind behavior; Fully configurable data reception for each supported protocol; Interface and protocol agnostic internal data model; Configuration data management for each supported protocol; Flexible local data buffering; Server- and network agnostic, plugin-based uplink.

3 Materials and methods

The most commonly used GW concepts were reviewed from the literature and compared with the requirements of mining applications. A new GW software supporting CANopen, raw CAN and J1939 was developed according to the identified requirements. The developed SW is hardware agnostic and thus tested first in a PC with Windows 10 and then in an embedded HW running Ångström Linux. Field testing was performed first in few assets and later number of assets was increased. Configuration workflow with conversion tools from corresponding standard network projects were developed.

4 Results and conclusions

The developed GW enabled an efficient adaptation of various kinds of assets to a back-end infrastructure. Implemented abstraction of information into signal samples and forwarding of the selected signals only enabled optimal use of the constrained communication resources from the field to the back-end. Typical configuration inconsistencies were avoided by relying on the standard processes and description formats of the selected network types. Computer aided generation of GW configurations from the validated communication descriptions lead into error free conversions and efficient deployments of heterogenous fleets.

5 Bibliography

- [1] Ding J., Nemati M., Ranaweera C., Choi J., IoT Connectivity Technologies and Applications: A Survey, IEEE Access VOLUME 8, IEEE, 2020
- [2] Strauß P., Schmitz M., Wöstmann R., Deuse J., Enabling of Predictive Maintenance in the Brownfield through Low-Cost Sensors, an IIoT-Architecture and Machine Learning, IEEE International Conference on Big Data (Big Data), IEEE, 2018
- [3] Poulter A. J., Cox S. J., Enabling Secure Guest Access for Command-and-Control of Internet of Things Devices, IoT Journal, Volume 2, Issue 2, MDPI, 2021
- [4] Tsiknas K., Taketzis D., Demertzis K., Skianis C., Cyber Threats to Industrial IoT: A Survey on Attacks and Countermeasures, IoT Journal, Volume 2, Issue 1, MDPI, 2021
- [5] Recommended Practice for Control and Communications Network for On-Highway Equipment, J1939-01, SAE, 2000
- [6] Brous P., Janssen M., Herder P., The dual effects of the Internet of Things (IoT): A systematic review of the benefits and risks of IoT adoption by organizations, International Journal of Information Management 51 (2020) 101952, Elsevier, 2022
- [7] Matikainen R., Bäckström C., Heiskanen R., Koski V., Sundquist P., Valtakari U., Kaivos- ja louhintatekniikan käsikirja, Vuorimiesyhdistys Ry., 1982, 802 p. (in finnish)

- [8] FMS-Standard description, Version 04, ACEA Task Force HDEI/BCEI, 13.10.2017
- [9] Vehicle Application Layer, J1939-71, SAE, 2006
- [10] Kang B., Choo H., An experimental study of a reliable IoT gateway, *ICT Express* 4 (2018) 130–133, Science Direct, 2017
- [11] Yacchirema D. C., Palau C., Smart IoT Gateway For Heterogeneous Devices Interoperability, *IEEE LATIN AMERICA TRANSACTIONS*, VOL. 14, NO. 8, IEEE, 2016
- [12] Beniwal G., Singhrova A., A systematic literature review on IoT gateways, *Journal of King Saud University – Computer and Information Sciences* 34 (2022) 9541–9563, Science Direct, 2021
- [13] Zyrianoff I., Heideker A., Silva D., Kleinschmidt J., Soininen J., Salmon Cinotti T. and Kamienski C., Architecting and Deploying IoT Smart Applications: A Performance–Oriented Approach, *Sensors* 2020, 20, 84, MDPI, 2020
- [14] Banaie F., Mistic J., Mistic V.B, Moghaddam M. H. Y., Seno S. A. H., Performance Analysis of Multithreaded IoT Gateway, *IEEE INTERNET OF THINGS JOURNAL*, VOL. 6, NO. 2, IEEE, 2019
- [15] Pradeep P. Kant K., Conflict Detection and Resolution in IoT Systems: A Survey, *IoT Journal*, Volume 3, Issue 1, MDPI, 2022
- [16] Bröring A., Schmid S., Schindhelm C., Khelil A., Käbisch S., Kramer D., Le Phuoc D., Mitic J., Anicic D., Teniente E., Enabling IoT Ecosystems through Platform Interoperability, *IEEE SOFTWARE* 0740-7459/17/\$33.00, 2017, IEEE
- [17] Aziz A., Schelén O., Bodin U., A Study on Industrial IoT for the Mining Industry: Synthesized Architecture and Open Research Directions, *IoT Journal*, Volume 1, Issue 2, MDPI, 2020
- [18] Sifakis J., System Design in the Era of IoT — Meeting the Autonomy Challenge, *Electronic Proceedings in Theoretical Computer Science*, Open Publishing Association, June 2018
- [19] Gelenbe E., Nakip M., Czachórski T., Improving Massive Access to IoT Gateways, *Journal of Performance Evaluation* 157–158 (2022) 102308, Elsevier, 2022
- [20] Papcun P., Kajati E., Cupkova D., Mocnej J., Miskuf M., Zolotova I., Edge-enabled IoT gateway criteria selection and evaluation, *Concurrency and Computation: Practice and Experience* 2020;32:e5219, Wiley, 2019
- [21] Kang B., Kim D., Hyunseung Choo H., Internet of Everything: A Large-Scale Autonomic IoT Gateway, *IEEE TRANSACTIONS ON MULTI-SCALE COMPUTING SYSTEMS*, VOL. 3, NO. 3, IEEE, 2017
- [22] Abboud K., Li Y., Bermudez S., eSNAP: Enabling Sensor Network Automatic Positioning in IoT Lighting Systems, *IEEE INTERNET OF THINGS JOURNAL*, VOL. 7, NO. 10, IEEE, OCTOBER 2020
- [23] Khaled A. E., Helal A., Lindquist W., Lee C., IoT-DDL —Device Description Language for the “T” in IoT, *IEEE Access*, VOLUME 6, IEEE, 2018
- [24] Saha H., Automated workflow for generation of CANopen system monitoring GUI, *Proceedings of the 17:th international CAN-Conference, CAN in Automation*, 2020
- [25] Fellmeth P., Löffler T., Networking Heavy-Duty Vehicles Based on SAE J1939, Technical Article, Vector Informatik GmbH, 12p