Riku-Pekka Nikula*, Marko Paavola, Mika Ruusunen, Joni Keski-Rahkonen

Towards online adaptation of digital twins

Keywords: adaptation, differential evolution, digital twin, optimization, surrogate model

***Corresponding Author: Riku-Pekka Nikula:** Control Engineering, Environmental and Chemical Engineering, University of Oulu, P.O. Box 4300, 90014 Oulu, Finland, E-mail: riku-pekka.nikula@oulu.fi

Co-authors: Marko Paavola, Mika Ruusunen, Control Engineering, Environmental and Chemical Engineering, University of Oulu, P.O. Box 4300, 90014 Oulu, Finland, E-mail: forename.surname@oulu.fi

Joni Keski-Rahkonen, Kongsberg Maritime Finland Oy, P.O. Box 220, 26101 Rauma, Finland, E-mail: joni.keski-rahkonen@km.kongsberg.com

1 Background

Digital twins, a core component of cyber-physical systems, have gained a lot of attention recently. However, in the utilization of the technology on industrial applications, practical challenges arise from the continuous and real-time data integration. These challenges appear especially in the simulation and optimization and their integration with the continuous flow of data from the physical system.

The physics-based simulators tend to be computationally burdensome and not necessarily optimized for fast iterative computations. In addition, the current adaptation methods have great challenges to meet the real-time requirements in the applications, where the significant phenomena occur at rates from hertz to several kilohertz. Therefore, the research on real-time data integration is urgently needed to enable the development of practical digital twin applications.

This study focuses on the real-time adaptation of digital twins based on a mechanism guided by evolutionary optimization. The adaptation is required since the physical object is exposed to external impulses unknown to the presumed system state in the digital twin. The digital twin requires timely adjustment in order to adapt to the unpredictable changes observed in the state of the physical object.

2 Materials and methods

The proposed adaptation mechanism evaluates the deviation between the measured state of the real system and the estimated state provided by the model under adaptation. The deviation is minimized by adapting the model input based on an optimization algorithm. Differential evolution was selected as the optimization algorithm due to its impressive properties for multi-parameter global optimization.

The mechanism was tested by applying it on data generated via simulations. A physics-based model compiled in Simulink® environment was transformed into a lighter modeling approach, namely a surrogate model, to speed-up the iterative computations. This simplified model of the physical system was then used to test the adaptation mechanism.

The case study presents a digital twin application for a marine thruster. This novel product digital twin is developed to support the maintenance and lifecycle management of the physical products. The physical models in the digital twin enable torque estimation in the driveline also in the positions where the in situ measurement is not practical.

The adaptation mechanism was used to estimate constant values that represented the values of a model input variable in short time windows. The torque at the propeller was selected as the adapted input variable in the case study.

3 Findings and conclusions

The results reveal that low errors were achieved in the surrogate model output and in the estimated input variable. However, the real-time requirement was not achieved with the applied settings. Therefore, additional research should be done to reduce the computational time. Possible solutions include parallel processing, hardware-based speed improvements, algorithm optimization and the use of more efficient programming techniques. The application of the proposed mechanism on more complex problems and other practical digital twin applications is encouraged.

Pekka Isto*, Tapio Heikkilä, Aarne Mämmelä, Mikko Uitto, Tuomas Seppälä, Jari M. Ahola

5G Based Machine Remote Operation Development Utilizing Digital Twin

Keywords: 5G, remote operation, models, control

***Corresponding Author: Pekka Isto:** VTT Technical Research Centre of Finland Ltd, Kaitoväylä 1,FI-90571 Oulu, Finland, E-mail: pekka.isto@vtt.fi

Co-authors: Tapio Heikkilä, Aarne Mämmelä, Mikko Uitto, Tuomas Seppälä, Jari M. Ahola

Extended abstract. Remote mobile machinery operations require reliable and flexible communication. 5G networks provide ultra-reliable and low latency wireless communications upon which remote operations, real-time control and data acquisition can be implemented. In this paper we present a demonstration system for remote machinery control with 5G radio and Hardware-in-the-Loop development system (Figures 1 and 2).

Nokia's 5G proof-of-concept (PoC) radio is utilised in the demonstration. It consists of base transceiver station (BTS) and user equipment (UE) units forming the actual wireless radio link fulfilling the 5G requirements. This first evolution concept of 5G radios optimises the system communication paths and exploits the massive MIMO beamforming. The radio part is run at 3.95 GHz center frequency with 200 MHz bandwidth enabling as low as 1 ms delay in the link and increased capacity up to several Gbps compared to present LTE.

Actual machine control systems are connected to a dynamic simulation system for Hardware-in-the-Loop development. The test system is based on a real embedded machine control system relying on CAN-bus. Remote control has been implemented by bridging the complete CAN traffic over TCP/IP and the 5G radio. For haptic control, an additional HMI controller was added to control 3 degrees-of-freedom of the machine.

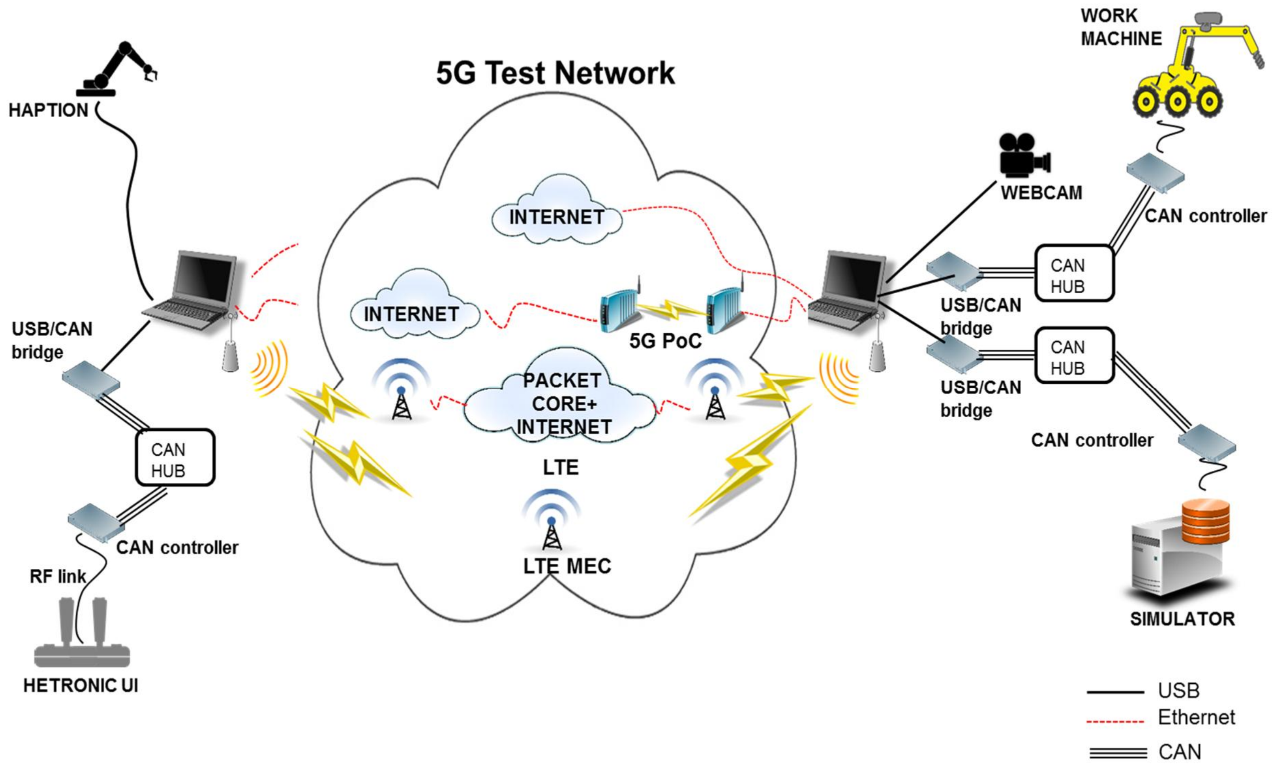


Figure 1. Remote operation of mobile machinery over the 5G networks and the internet..

ISBN 978-952-5183-56-6

Figure 2. 5G Proof-of-Concept radio.

Figure 3. Remote control station with haptic control.

Figure 4. Hardware-in-the-Loop simulator in the remote site.

Jouni Aro*, **Markus Johansson**

Simulation Platform for Industrie 4.0 Components with OPC UA

Abstract: OPC UA has been defined as the Industrie 4.0 Communication and will be the major requirement for all Industrie 4.0 Components. This paper describes a platform that will enable simulating any industrial system based on the OPC UA information modelling concepts. Simulation will help in building and testing new Industrie 4.0 Components in practice.

Keywords: Industrie 4.0, Smart Manufacturing, OPC UA, Administration Shell, Communication, Information Model, Simulation

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

Markus Johansson: Prosys OPC Ltd, E-mail: markus.johansson@prosysopc.com

1 Background

Manufacturing is moving towards more flexible production lines that enable more customized products that are produced per order rather than to the storage as is the case with traditional mass production.

To enable this kind of improved flexibility, manufacturers are defining new production lines that are based on modular assembly cells and automatically guided vehicles (AGVs) that move the products from one cell to the next according to the production specification of each product. Some system providers are also defining agent-based manufacturing execution systems (MES) where each component on the production line can take and give production orders from each other.

Industrie 4.0 is a German program which is defining a Reference Architecture Model for Industrie 4.0 (RAMI 4.0) to outline how various standards will be used to enable a common framework for a future factory.

Industrie 4.0 Component is any device or software component that fulfils the RAMI 4.0 requirements. The components are expected to provide an Administration Shell that defines a standard interface for configuring and accessing all information of them. This enables flexible production lines that can be customized for individual production orders and smaller lot sizes.

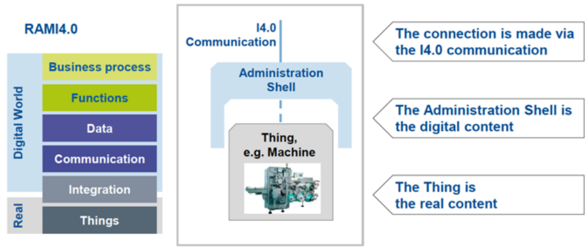


Figure 1. Administration Shell is the digital part of an Industrie 4.0 Component.

OPC Unified Architecture (OPC UA, IEC 62541) is a standard that has been selected to be used for Industrie 4.0 Communication. In addition to standardizing communication, it also defines a standard semantic modelling layer, which can be used to provide a common information modeling layer for RAMI 4.0.

2 Aim

This paper describes a platform that will enable simulating any industrial system based on the OPC UA information modelling concepts. Simulation will help in building and testing new Industrie 4.0 Components in practice.

OPC UA enables modeling of device and machine types and instantiation of these types. For example, as described in Figure 2, MotorType defines a generic model for a motor and Motor1 is a single instance of an actual motor.

OPC UA Information Models are typically specific semantic models, in other words collections of type definitions. OPC Foundation defines a standard model, which is the basis of all other models. Companion Models are domain specific models that are defined by domain organizations, such as PLCopen, ISA-95, PackML, etc. Vendors and users can also define their own models that define types that derive from other models.

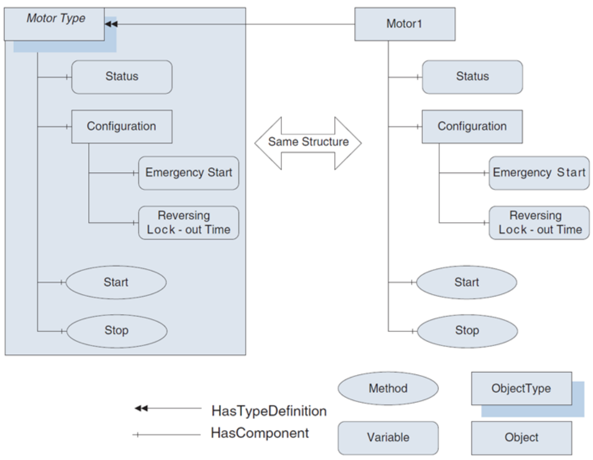


Figure 2. MotorType and Motor1 instance as defined in OPC UA notation.

In order to help designing new OPC UA Information Models and the functionality of actual instances of the respective types, a simulation platform is designed to enable flexible definition of simulated data to be attached to data items of the instances.

In practice, the system will also enable realistic reflection of real devices and can be used for off-line development of other systems and applications that will communicate with these kinds of devices in real world.

3 Methods

The simulation is based on Prosys OPC UA Simulation Server [1], which is extended with a graphical user interface that enables configuration of a complete production line or smaller parts of the component hierarchy. The system will also enable importing structures of actual installations as described in Figure 3. The simulation platform enables configuration of data simulation per component type or individual components [2], so that it can be easily scaled to larger installations and customized according to specific needs.

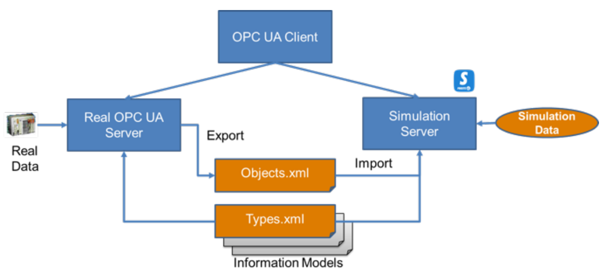


Figure 3. Reflection of a Real OPC UA Server with the Simulation Server. OPC UA Clients can connect to either the real or simulation server to get similar data.

4 Future Development

Once the system enables configuration of various device and production line structures, the system can also be developed towards more complex simulation signals. This will enable more realistic simulation of device and system functionality as well.

References

1] Boström B., JavaFX based OPC UA Simulation Server, M.Sc. thesis, Aalto University, Espoo, 2014
2] Saikko L., Simulating OPC UA Information Models, M.Sc. thesis, Aalto University, Espoo, 2018

Amin Modabberian, Hoang Khac Nguyen, Kai Zenger

Mean Value Modelling of Maritime Diesel Engines

Corresponding authors: Amin Modabberian: Aalto University, email: amin.modabberian@aalto.fi

Hoang Khac Nguyen: Aalto University, email: hoang.kh.nguyen@aalto.fi

Kai Zenger: Aalto University, email: kai.zenger@aalto.fi

Keywords: diesel engines, modelling, mean value modelling

Extended abstract

As the European emission standards have become more restricted, diesel engines are becoming obsolete especially within the automotive industry [1]. However, diesel engines will be used in maritime transportation for the upcoming decades. Emission minimization of NO_x, CO_2 and particulate matter is one of the major areas in maritime diesel engine control applications. Adhering to emission conditions set by International Maritime Organization (IMO) [2], current diesel engines requires efficient control, which itself requires accurate modelling.

In this work, a first principle mean value model for diesel engine airpath and engine dynamics are presented, that is, creating a nonlinear and linear models to examine the state variables of the systems, which are intake and exhaust manifold pressures, compressor power and engine speed. The airpath model consists of intake and exhaust manifold pressures, turbocharger power, engine speed and fuel injection ratio. Each dynamics is modeled and simulated separately utilizing MATLAB's Simulink. Some the models are achieved empirically due to nonlinearity of the system. On the other hand, such nonlinear models are required for mapping complex chemical and combustion reactions. Mean value model itself is a valid approach. However, it is not suitable for cylinder-wise control, since it does take the pulsating nature of the engine airpath in to account [3][4].

In general, modeling does not possess a single way approach for all dynamic systems. However, numerous valid and widely used approaches exist in the literature [5-9]. Each system and its features, such as physical quantities mentioned above, requires a careful and systematic approach, which affects the control design and behavior of control. In other words, the desired efficiency in control design of the engine is highly dependent on the generated mathematical models of the system. Mean value models are also part of the more accurate models to be developed for cylinder-wise control of the engine, which is a key challenge nowadays and in the years to come [10].

References

[1] Emission in the automotive sector. https://ec.europa.eu/growth/sectors/automotive/environment-protection/emissions_en

[2] International Maritime Organization, Nitrogen Oxides (NOx) – Regulation 13. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx

[3] J. Aalto-Setälä. Adaptive wastegate control of combustion engines, 2013.

[4] S. Samokhin. Adaptive control of conventional and hybrid marine diesel engines subject to uncertain or time-varying dynamics. Phd thesis, Aalto University, 2018.

[5] A. G. Stefanopoulou, I. Kolmanovsky, and J. S. Freudenberg. Control of variable geometry turbocharged diesel engines for reduced emissions. In Proceedings of the 1998 American Control Conference. ACC (IEEE Cat.No.98CH36207), volume 3, pages 1383–1388 vol.3, June 1998. 10.1109/ACC.1998.707043.

[6] M. Jankovic and I. Kolmanovsky. Robust nonlinear controller for turbocharged diesel engines. In Proceedings of the 1998 American Control Conference. ACC (IEEE Cat.No.98CH36207), volume 3, pages 1389–1394 vol.3, June 1998. 10.1109/ACC.1998.707047.

[7] M. Jung and K. Glover. Calibratable linear parameter-varying control of a turbocharged diesel engine. IEEE Transactions on Control Systems

Technology, 14(1):45–62, Jan 2006. ISSN 1063-6536. 10.1109/TCST.2005.860513.

[8] A. Plianos and R. Stobart. Dynamic feedback linearization of diesel engines with intake variable valve actuation. In 2007 IEEE International Conference on Control Applications, pages 455–460, Oct 2007. 10.1109/CCA.2007.4389273.

[9] L. Kocher, E. Koeberlein, K. Stricker, D. G. Van Alstine, B. Biller, and G. M. Shaver. Control-oriented modeling of diesel engine gas exchange. In Proceedings of the 2011 American Control Conference, pages 1555–1560, June 2011.10.1109/ACC.2011.5991425.

[10] Gabriel Turesson. Model-Based Optimization of Combustion-Engine Control. PhD thesis, Lund University, 06 2018.

Pasi Ojala*

Machine Learning for Intelligent Maintenance

Abstract: In this publication, we introduce how Efora is applying predictive analytics and machine learning in intelligent maintenance. We apply non-supervised methods to train models for anomaly detection and failure prediction. The approach has proven to work as evolving issues have been found and fixed before problems in production appeared.

Keywords: Predictive maintenance, machine learning, anomaly detection

***Pasi Ojala:** Efora Oy, E-mail: pasi.ojala@efora.fi

1 Introduction

Our requirements for asset availability are set high to ensure efficient operations without production loss. Development work on maintenance processes has driven the number of systematic problems low. Known issues on process lines have been already been identified and handled with scheduled preventive maintenance process. Root cause analysis and continuous improvement methods are applied to tackle them. The problem is with wearing components, unexpected technical failures and events that occur rarely or that have never been seen before. To reach availability targets, even these cases need to be handled.

2 Predictive maintenance

Maintenance process is driven by decisions that are based facts found in data. And when going beyond signal trending and thresholding, we need machine learning based solutions.

Typical supervised machine learning requires vast amounts of training data and labelling information from past process failures. However, when facing unexpected issues and rare events, the problem becomes far more complex. Unsupervised learning is needed. And instead of failure prediction, the analytics should inform maintenance personnel about upcoming risks. Human factor is needed to make decisions based on findings. Therefore, the solution combines our process knowledge with advanced analytics.

3 Machine learning solution

We have built machine learning based solutions that compare actual process measurements to model output, detect evolving anomalies, find causal relationships to the change, and reveal the possible root cause of the problem. Due to the dynamic nature of the process, we apply Recursive Neural Networks (RNN) for modelling and prediction. Well trained autoencoder is able to detect even minor anomalies and evolving issues. Maintenance experts use the analytics tools to get prewarning on possible problems, pinpoint the issue and schedule required preventive actions.

4 Anomaly detection

We have managed to find unexpected issues in the production line with anomaly detection tool. Even with limited coverage, the system has successfully detected sensor failures, process malfunctions, and eventually, prevented production losses. Figure 1 presents an example of an evolving issue in web profile control in Steambox. In this case, the trained autoencoder model detected a process anomaly soon after a production break. The process appears to work normally, but based on earlier learnings, the unsupervised process model is expecting nearly constant steam consumption in web profile control while the measurement indicates a slight increase. Since the measurement is well within typical operation point and in acceptable range, the process control did not issue any alarms. Hence, it is not possible to see process deviation simply by following measurement trends. However, trained process model disagrees with the measurement. In this case, operational problems were already present further in the production line.

The process anomaly of Figure 1 was detected with autoencoder, and the true root cause was found by analyzing related measurement trends. The evolving problem was fixed immediately and production loss was avoided.

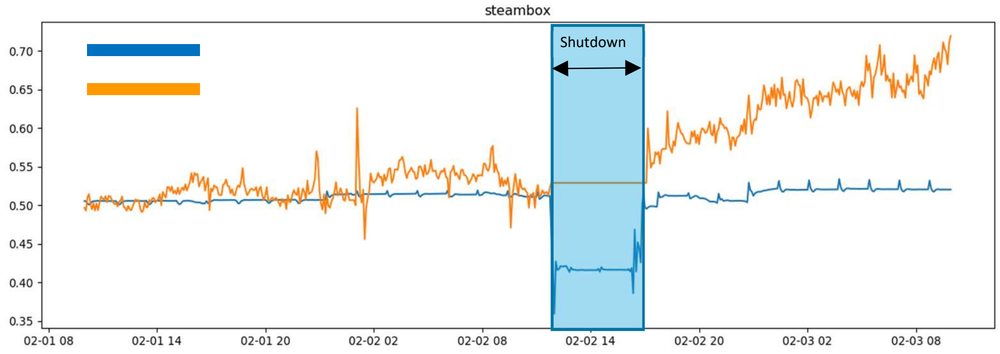


Figure 1. Evolving anomaly in Steambox.

5 Next steps

The system is being developed further based on user experiences on the new way of working and bases on how the analytics tools are being applied. The system is constantly learning when domain expert input and model findings are combined. Results from the analytics can be directly mapped to failure notifications and preventive maintenance work orders in ERP as well as diagnosis done by the maintenance experts. As a result, our solution reduces laborious routine work when large data mass can be analyzed automatically and findings can be fed directly to preventive maintenance process.

Samuli Bergman*, Tomi Lahti, Alexandre Boriouchkine, Toni Oleander

Artificial Intelligence and Machine Learning in Process Industry

Keywords: Machine Learning, Process Optimization, OPC UA, Industrial Application

***Corresponding Author: Samuli Bergman**, Neste Engineering Solutions Oy
E-mail: Samuli.bergman@neste.com

Other Authors: Tomi Lahti, Alexandre Borouchkine, Toni Oleander, Neste Engineering Solutions Oy,
E-mail: tomi.lahti@neste.com

1 Introduction

Many actors in chemical process industry think that the profitability of their plant has reached the maximum level, but by utilizing machine learning and artificial intelligence it is possible to take the profitability to the next level. It is crucial for competitiveness to guarantee the profitability of the production under any circumstances. As market prices of feedstock fluctuate and operating conditions vary, this has become more and more challenging.

The objective of the usage of machine learning (ML) and artificial intelligence (AI) is to refine data and turn it to valuable information, knowledge and insight that help either to run the plant in a more optimal way, to detect and identify abnormal events or to do maintenance at the most ideal time-point (prescriptive maintenance). There exist real-life process industries challenges that can be solved with ML and AI which have own characteristics that need to be taken into account. Especially implementing ML and AI requires big amounts of data for model creation and streaming data for actual AI deployment, so up to date operational production data infrastructure is essential for success.

2 All starts with data

The first practical challenge is to access all relevant and available data. Traditionally plant operation (or process-related decision-making) is mostly based on process measurements in the process control system (DCS). However, other data sources are often needed to get a full picture on all the related circumstances. Such sources are e.g. laboratory information management system (LIMS) or data on logistics operations in enterprise resource planning system (ERP). Modern IT communication technologies, such as OPC UA, enable safe and secure communication between these different systems and the digitalization platform.

3 Know your context

Another challenge is caused by complex interactions and dynamic phenomena present in chemical processes. Whereas typical process instrumentation enables monitoring of hundreds of temperatures, pressures, flow rates or liquid levels in a single operating unit, these quantities only contain a weak and variant correlation with many economically important phenomena. Examples of such important phenomena are e.g. side- and by-reactions caused by some substances present in very low concentrations in the feedstock; slow degradation of reactor catalyst because of poor operation conditions; fouling of process equipment; or circumstances that create corrosion. Data-based methods can help to solve this challenge. Models based on artificial intelligence, machine learning in particular, have proven to be powerful tools for refining the data into information on unhidden phenomena that cannot be directly observed by monitoring the time series of single measurements. This is, however, not enough, but the insight on hidden phenomena must be available in real-time. The key benefits will be achieved only if this real-time insight is utilized continuously by advanced optimization and automation solutions to push the process towards the optimum. In conclusion, with the help of artificial intelligence and machine learning it is possible to better understand what currently goes on in processes and in process equipment, and this knowledge enables to better foresee the future and to optimize the operative actions. This means that the production can be run at the maximum level with the maximum profit safely.

4 Know your business

Third challenge is posed by the need to operate plants in an agile operations way. The market demands vary, which is materialized in the plant floor level by a wide variety of different product specifications. At the same time, the feedstock palette has become more volatile. E.g. oil refining industry is featured by two trends. Firstly, heavier crude oils with higher sulfur content need to be processed and, secondly, different bio-based feedstocks are used more and more. This means that processes are more often in a transient state and that optimal process conditions may be very different from the ones that have been accustomed with. Simultaneously a new generation of process operators is entering to the labor market. All this calls for redefining the way processes should be run and how operators could be assisted to perform their tasks in an optimal way. AI can be a beneficial tool in this. AI can learn best practices to operate process in various situations and help operators to achieve their targets. This type of applications builds a bridge between traditional paradigms of process modeling and competence development.

5 Conclusion

The use of artificial intelligence does not remove the need for human workforce, nor does it remove the responsibility of human operators. This makes the digitalization a leadership challenge. The new information that AI provides will change the way operators work. They need to understand the new methods and learn to trust this new information. Therefore, digitalization projects in chemical industry should never be left solely for ICT or automation departments. It pays off to involve plant engineers, shift supervisors and panel operators and trainers already in the early phases of digitalization.

Kari Rainio*, Jukka K. Nurminen, Jukka-Pekka Numminen, Timo Syrjänen, Niklas Paganus, Karri Honkoila

Machine learning for object detection in legacy P&I diagrams

Keywords: object detection, P&I diagrams, machine learning, legacy data

***Corresponding Author: Kari Rainio:** VTT, E-mail: Kari.Rainio@vtt.fi
Jukka K. Nurminen: University of Helsinki, E-mail: Jukka.K.Nurminen@helsinki.fi
Jukka-Pekka Numminen: Pöyry Oy, E-mail: jukka-pekka.numminen@poyry.com
Timo Syrjänen: Pöyry Oy, E-mail: timo.syrjanen@poyry.com
Niklas Paganus: Fortum Oy, E-mail: niklas.paganus@fortum.com
Karri Honkoila: Fortum Oy, E-mail: karri.honkoila@fortum.com

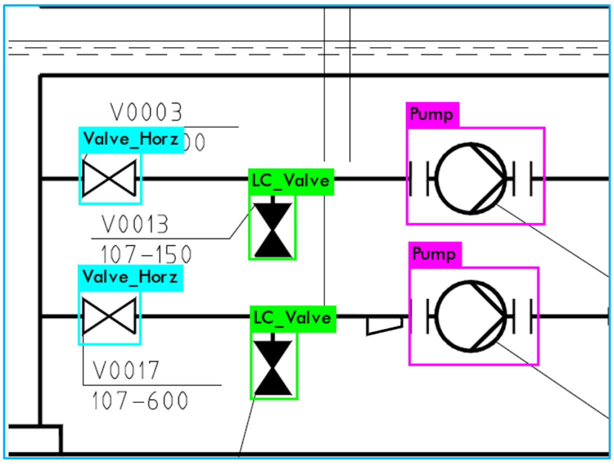


Figure 1. Example of component detection in P&I diagram

1 Background

Over the years companies have accumulated large amounts of legacy data. The data can contain useful information but is difficult to use because it is typically in paper or picture form. The goal of our research is to study ways to detect high-level objects from drawing data.

As an example, a process and instrumentation diagram (P&I diagram) in drawing form is just a set of points in pixel representation, or a set of graphical objects, like lines, arcs, or polylines, in vector presentation. To be useful this level is not enough. Instead we need to detect if the diagram contains higher level elements, such as pumps and valves (Figure 1).

2 Aims

In this work we wanted to see how the the modern machine learning based approaches, in particular, the Yolo neural network system [1], can be used for this task. The design goal of Yolo has been realtime detection of objects in video streams. It can analyze tens of pictures in a second making the algorithm useful e.g. for autonomous vehicle solutions where the speed is essential. For our needs, Yolo is an overkill. Time is not hugely critical for analyzing old diagrams. Our 2D drawing data is much simpler than 3D video feeds. On the other hand, Yolo is readily available and if it works well with our object detection tasks it can be used as such. If we easily can retrain it to detect all kinds of diagram symbols it has potential to be a versatile, adaptable tool for object detection in legacy diagrams.

We also wanted to explore the concept of using a simulator, in our case Apros, to generate labeled training material. Access to good quality training data is a frequent challenge in supervised learning and the use of artificially generated training data can be one solution.

3 Materials and methods

For our experiments we generated 2000 random Apros diagrams. To save training time we used only seven different component types. We selected these components with the aim to have some which are common and have simple symbols (e.g. ControlValve and CheckValve), some with more complicated symbols (e.g. Machinescreen2, LiquidEjector, GasEjector), and some with bigger symbols (Tank). The idea was to try out how the symbol size, complexity, and similarity to other symbols influence the detection.

To validate the concept with real-world data we also used components from Pöyry component library. Alto-

Extended Abstracts
ISBN 978-952-5183-56-6

gether it contains around 800 different symbols. However, we limited ourselves to 200 most commonly used symbols.

We converted these symbols to Apros custom components and generated 20.000 random diagrams for training. We then tested the trained network with legacy diagrams from past Pöyry projects. Because of the large number of components and needed training instances we used Azure instances which provided support for GPUs. The use of GPUs has a dramatic effect on training speed with approximate 50x speed increase for training. We ran 250.000 training iterations which took about 24 hours.

4 Results

As shown in Figure 2 the system is good at detecting large components. It is able to deal with complicated symbols, overlapping texts, and lines.

However, the system has problems with smaller components, and it is not able to detect the smaller components in Figure 2. The reason for this is that we need to reduce the resolution of the picture before it is provided as input to Yolo system. As a result, with the new resolution the figure becomes quite blurry (as shown in Figure 3), and hard even for a human to classify. It would, of course, be possible to increase the resolution in the machine learning system but tt would increase the size of the neural network and the number of trained parameters dramatically. As a result much more training examples and computational power would be needed.

In our experiments we found that when components smaller that 15% of page size are hard to detect.

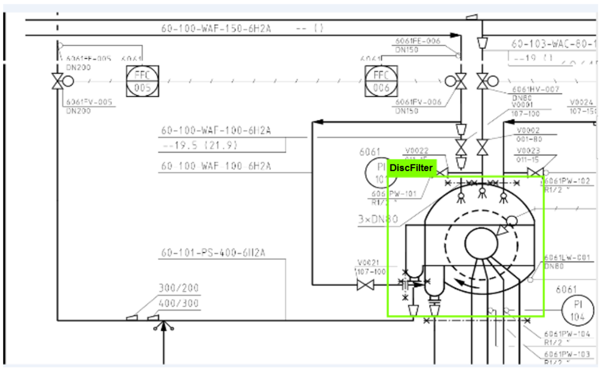


Figure 2. Example of detecting large and complicated components. However, Yolo misses most of the smaller components.

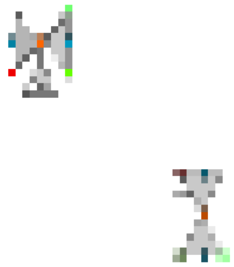


Figure 3. With reduced resolution small components become blurry and are difficult to detect correctly.

One solution is that we divide a big diagram into a set of smaller zoomed subdiagrams. Because the detection speed of Yolo is rapid, we can easily afford hundreds or even more subdiagrams to be analyzed and their results combined for the final result. Because the development of object detection systems is very active, Yolo can, in the future, be easily substituted with another more efficient and accurate machine learning system.

5 Future work

Besides object detection we have also evaluated the other subtasks needed for legacy data use (detection of connections and detection and OCR of text). In our future work we plan to put the different pieces together to create a system which can process legacy diagrams and convert them automatically into a standard form such as DEXPI. Then they can be used for different kind of tasks allowing companies to gain value from their legacy data.

References

[1] Redmon J, Farhadi A. YOLOv3: An Incremental Improvement. *arXiv*. 2018;.

Acknowledgements

This work was partly funded by Business Finland Engineering Rulez project.

Mingzhang Wu, Janne Koljonen, Timo Mantere*

Addressing Resource Allocation Issues in Cloud Computing Environment with Ant Colony Optimization

Abstract: Cloud computing is a fast growing and attractive paradigm in information technology, since it allows using resources on-demand wherever and whenever needed. The use of dynamic cloud resource allocation allows immediate accommodation to unpredictable demands and improvement in the return on investment as for the computing infrastructure. The cloud resources allocation optimization model is one of the core parts in cloud computing. However, despite the recent growth of the research in the cloud computing area, several problems with the process of resource allocation remain unaddressed. Cost and performance are two important but contradictive objectives in the cloud resources allocation process. Cost-performance trade-off constitutes a challenging multi-objective optimization problem in cloud resources allocation. In this paper, a new optimization model is proposed to solve this multi-objective optimization problem effectively. An ant colony optimization algorithm that optimizes the Quality of Service (QoS) and the response time in a simulated CloudSim environment that models five servers of varying characteristics. Experimental results demonstrate the effectiveness of the designed algorithms. Ant colony algorithm shows mostly higher performance than the round robin and greedy assignment algorithms that were used as benchmarks.

Keywords: ant colony optimization, cloud computing, CloudSim, cost-performance, resource allocation, trade-off problem

*Corresponding Author: Timo Mantere: University of Vaasa, School of Technology and Innovations, E-mail: timo.mantere@uva.fi

Mingzhang Wu: E-mail: mingzhang.wu@gmail.com

Janne Koljonen: University of Vaasa, School of Technology and Innovations, E-mail: janne.koljonen@uva.fi

1 Introduction

In the recent years, information technology (IT) has been integrated into our daily life more and more. The major applications are build up based on network and internet technologies. We are now in an era of “big data” with rapid growth on the number of transactions, information, and data. However, low cost, fast speed, and efficient computing are desired. The traditional network and local computation capacity are unable to meet these needs. Instead, distributed network technologies are developed to enable the utilization of distributed computing resources from the internet. How to integrate and distribute the resources, such as servers, over the internet give new research topics to be considered.

Cloud computing is a result of the convergence of several technologies, such as, (1) hardware, (2) internet technologies, (3) distributed computing, and (4) systems management. The main advantage of cloud computing is providing computing resources based on the public utility model (compare to water, electricity, gas, and telephony) to enhance reliability, scalability, and performance.

From the technical perspective, cloud computing is the integration of many aspects of technologies, such as (1) virtualization, (2) utility computing, and (3) distributed computing. From the business perspective, cloud computing is a new business model. It enables (1) sharing information among users, (2) buying resources on-demand without large investments, (3) selling capacity to many users, and subsequently (4) improving the return on investments due to better rates of capacity use. Furthermore, (5) investing on the latest, high-performance infrastructure should give a business advantage to the service provider.

Ant Colony Optimization (ACO)is inspired by the observation of the collaboration activities of ants searching for food. Ants can gradually find out the shortest path between a food source and the nest of the colony. ACO can be modeled as a graph, including resource assignment. However, in its original form, ACO modifies the edges of a graph, not the nodes as will be done in this paper.

2 Experimental setup

The role of ACO is tackle the Cost-Performance trade-off problem (CPTOP). First, the problem is transformed into a Travel Salesman Problem (TSP). Second, the separate objectives of cost and performance are integrated into a single objective function, which is then optimized in the CloudSim environment.

CloudSim provides many ways for managing and utilizing the resources, such as virtual machine (VMs), datacenter, etc. It offers: (1) support to modeling and simulation of a large cloud computing infrastructure, (2) a self-contained support data center, service agent, scheduling and allocation strategy platform.

As for the optimization, the objectives for the customers and the cloud service providers are different: The objective of the customer is to maximize the performance of resources with a fixed cost. For the cloud service provider, the total amount of resources is fixed, and the objective is to add as many customer requests to the cloud as possible.

The objective – an energy function – can be defined in terms of idle capacity, that is, unoccupied capacity that cannot be assigned to another VM due to limitations in some other resource type. The optimization then follows the principle of minimum energy.

3 Experiments and results

To test the algorithm, a small cluster scenario with five servers having different characteristics and a single type of virtual machine (VM) was used. To compare the ACO algorithm with other assignment schemes, the results with the round-robin and a customer greedy heuristic schemes were also tested.

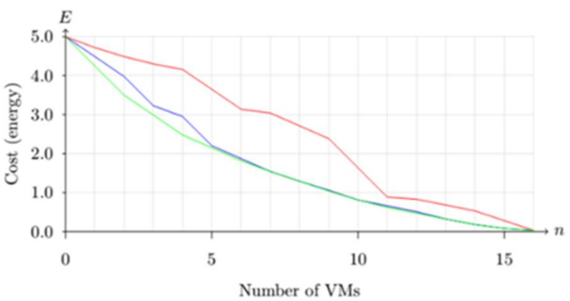


Figure 1. Comparison of the efficiency of the algorithms: round-robin (blue), greedy (red), and ACO (green).

Figure 1 shows the energy for each of the three assignment strategies for an increasing number of standard size VMs. The ACO algorithm described in this study (green line) has lower energy than the other two, although the round-robin strategy (blue line) is close to optimal. The greedy algorithm is evidently the worstof these three with practically any number of VMs.

4 Conclusions

Cloud computing enables a more efficient way to use utility computing resources and services. Users can access the computing resources with virtualized technologies and pay only for the resource accessed while getting the level of quality of service (QoS) wanted.

In this study, an optimal assignment was found by minimizing a combined energy function that measures cloud provider's costs. However, the test setup was relatively limited and simplified, due that a full-scale simulation of cloud computing services are complicated. The benefit for the cloud provider is to maximize the possibility to add further VMs to the existing cloud infrastructure without performance degradation or delays.

Three assignment policies were simulated and tested in CloudSim: round-robin, a customer greedy heuristic, and an optimized allocation implemented as an Ant Colony Optimization algorithm. When comparing the three assignment policies, the round-robin can be said to be both simple and efficient. The greedy assignment, where a customer can choose to allocate a VM to the host with the freest capacity was rather expensive. However, in this implementation, each processor had the same MIPS, so the results might be different in an environment with more versatile set of resources available.

The way that ACO uses resources differed in an optimal case from the round robin method only so that one extra VM was assigned to a different host. Nevertheless, this little change makes ACO to obtain the best energy function values. The further tests with varying numbers of VMs validated the mutual order of the three algorithms; ACO consistently outperforms the simple round-robin method slightly, while the round-robin method outperforms the simple greedy method significantly.

These experiments have some limitations. Actually, the implementation of ACO in CloudSim makes a solution 'all at once'. Therefore, it is recommended to develop an ACO variant that could find an optimal policy with a more dynamic situation, where VMs are created and terminated all the time.

Mika Karaila

Automaation tulevaisuus – Tekoälyn ja ihmisen vuorovaikutuksia

Avainsanat: tekoäly, pilvipalvelut, koneoppiminen, paperikone, katkoherkkyys

***Kirjoittaja: Mika Karaila:** Research Director,
E-mail: mika.karaila@valmet.com

Tiivistelmä: Uudet pilvipalvelut ja tekoäly tulevat, mitä se tarkoittaa automaatiossa. Tarvitaanko ihmistä prosessinohjauksessa, kuka tekee päätökset. Teollisen Internetin uudet pilvipalvelut on toteutettu koneoppimisen ja tekoälyn avulla. Paperiradan katkoanalyysi kertoo jo hyvällä todennäköisyydellä katkoherkkyden ja sen todennäköisen aiheuttajan. Nämä uudet tuotteet perustuvat erilaisiin koneoppimisen algoritmeihin ja tarjoavat aivan uudenlaisia sovelluksia, joiden avulla asiakkaat voivat ajaa konettaan. Muita uusia mahdollisuuksia tekoäly tuo ongelmien ratkaisuun erilaisissa olosuhteissa, joissa ns. Expert – tekoäly-pohjainen avustaja voi jutella käyttäjän kanssa ja hakea erilaisia vaihtoehtoja tai jopa ehdottaa ongelmaan jotain löytämäänsä ratkaisua.

1 Johdanto

Perinteinen automaatio on muuttunut yksikkösäätimistä ja perinteisistä PID-säätimistä monimuuttuja säätimiin ja muihin mallipohjaisiin säätöihin. Automaatioaste on erittäin korkea nykyaikaisissa tehtaissa ja seuraava nähtävissä oleva kehitys vie ratkaisuja pilvipohjaisiin / Edge-tason ratkaisuihin. APC-säätöjen lisäksi haetaan sopivaa tasoa ja toteutusta, jonka avulla automaatiosta osa voisi olla hajautettuna tehdaan ulkopuolelle.

Tässä käsitellään uusia ratkaisuja, jotka pohjaituvat tekoälyyn ja miten ne kehittyvät automaation mukana. Ihmisen vaikutus ja päätöksen teko tulee olemaan oleellinen osa. Mallipohjainen ja APC-säädöt toimivat matemaattiset suunnitellun mukaisen kiinteän ratkaisun pohjalta. Kun tätä verrataan tekoälyyn pohjautuvaan säätöön, joka on voitu ensin opettaa ja validoida kerätyn datan perusteella on huomioitava seuraavat asiat:

- Säätö perustuu opetusdataan, jos siinä on puutteita säätö ei voi toimia ko. tilanteissa.
- Jos ympäristö (prosessi) muuttuu, ei opetusdata ole enää oikeaa.
- Muut epäjatkuvuuskohdat ja anomaliat, joista ei ole ollut opetusdataa pitää huomioida säädössä, jotta voidaan varmistaa ettei säätö toimi väärin näissä tilanteissa.

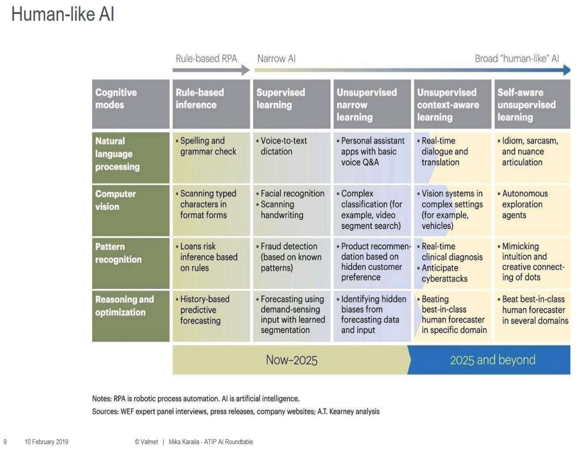
Kun yllä olevat tiedostetaan on hyvin ymmärrettävää että vastaavalla tavalla kuin autonomisen auton kanssa ihmisen on koskettava ohjausrattia n. 10 sekunnin välein tarvitaan automaation tekoälyssä myös ihmistä, jonka näkymys ja laaja tietotaito on varsinainen päätöksen tekijä prosessin ohjauksessa.

Toisaalta kun ajatellaan miten tekoäly voi auttaa ihmistä prosessin ohjauksessa pitää huomioida, että tekoälyllä on seuraavat hyvä puolet:

- Ihmistä parempi muisti eli usean vuoden ajalta kerätty data sekä omalta tehtaalta ja mahdollisesti muilta tehtailta on enemmän kuin ihminen todennäköisesti voi muistaa.
- Eri tavoitteiden tarkastelu oikein toteutettuna voi hakea paremman optimitilanteen tai tavoitteen kuin on ihmisen tiedossa. Joissain tilanteissa ihminen näkee 1. tason tavoitteen, mutta algortimi voi hakea optimaalista 2. tason tavoitetta, jossa on huomioitu sekä raaka-aineet että energian käyttö. Lisäksi monessa tilanteessa operaattori ajaa ensisijaisesti häiriötöntä tuotantoa (todennäköisesti mm. paperin tuotannossa hieman parempaa laatua, koska ei halua ratakatkoja vaikka tekoäly pystyy ajamaan enemmän kierrätyskuidulla tuotettua paperia).
- Yleisesti voidaan todeta että tekoäly toimii paremmin suppean alueen sanaston ja ongelman käsittelyssä, jossa ulkoisia tekijöitä on pystytty rajoittamaan

Ihmismäisen tekoälyn toteuttamisessa tarvitaan luonnollisen kielen ymmärtämistä sekä sen ”puhumista”, tätä selventää alla oleva Kuva 1 Ihmisen kaltainen tekoäly.

ISBN 978-952-5183-56-6



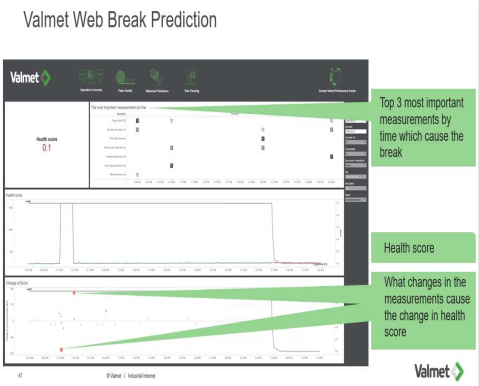
Kuva 1. *Ihmisen kaltainen tekoäly*

2 Tekoäly automaatiossa ihmisen apuna

Tekoälyn liittäminen automaatioon tai sen käyttö eri tavoin voidaan toteuttaa käyttämällä valmiita tekoäly algortimeja ja työkaluja:

- Katkoanalytiikka on koostettua monesta eri algoritmista, jotka hakevat prosessin herkkyyttä ja siihen vaikuttavia muuttujia.
- Valmet Expert, joka perustuu ihmisen keräämään tietoon ja olemassa oleviin asiakastapauksiin, ongelmasta ja sen ratkaisusta.

Katkoanalytiikassa on ensin valittava ne mittaukset ja säädöt, joiden perusteella data-analyysi voidaan tehdä ja kouluttaa. Vasta tämän jälkeen tekoälyalgoritmi voidaan kouluttaa opetusdatan avulla, jotta ne löytävät erilaisia katkoja. Näiden tunnettujen katkojen tietojen perusteella saadaan viritettyä neuroverkko sille tasolle että ennustemalli pystyy varoittamaan operaattoria 1-2 tuntia ennen mahdollista katkoa tilanteen, Kuva 2 Katkoanakytiikan käyttöliittymä. Malli pystyy näin koulutettuna antamaan operaattorille ne prosessimuuttujat (root cause parameters), jotka vaikuttavat eniten ko. katkon ennusteeseen.



Kuva 2. *Katkoanakytiikan käyttöliittymä*

Yllä kuvattu paperikoneen katkoanalytiikka ei ole kuitenkaan yleispätevä. Siitä on tehty oma versio pehmopaperikonetta varten. Systeemidynamiikan takia näistä on tehty erilliset, jotta ennusteen tarkkuus on saatu tarpeeksi tarkaksi. Lisäksi ko. mallit eroavat myös opetusdatan osalta.

Avustava tekoäly, joka voidaan tuoda eri käyttöliittymiin, joko Web-selaimen avulla chatbot-tyylisenä tai VR-ympäristöön Avatar:ina on yleisti käsitelty kirjassa [1] ja artikkelissa [2]. Kuva 3 Ihmisen kaltainen "chat-bot" on yksi edistyneempi proto-tyyppi, jossa kysymys – vastaus pohjainen tekoäly osaa vastata muutamaan paperikoneen huoltoon liittyvään kysymykseen. Kuva 4 Valmet Expert avatar: ihminen tai tekoäly avustajana on yksinkertaisempi grafiikaltaan, mutta kollaboraatio toisen ihmisen kanssa on tehokkaampaa kuin tekoälyn kanssa.

Kuva 3. *Ihmisen kaltainen "chat-bot"*

Kuva 4 *.Valmet Expert avatar: ihminen tai tekoäly avustajana*

3 Toteutuneet tekoälypohjaiset sovellukset

Katkoanalytiikkaa voidaan käyttää paperikoneen sekä pehmopaperikoneen katkojen ennustamiseen. Tämän hetken rajoitteena on saada ensin luotettava ennustemalli viritettyä. Tämä vaatii siis opetusdataa ja sen painokertoimien korjaamisen data-analyytikon toimesta. Alkutilanteessa ennusteen tarkkuus oli vain hieman yli 20%. Kuitenkin kun malli on saatu tehtyä ja se on validoitu muutamaan kertaan sen luotettavuus on yli 50%. Näihin mallin antamien juurisyiden tulkintaa tarvitaan ensin prosessiasiantuntijaa auttamaan asiakasta ymmärtämään mitä ko. tilanteessa pitää tai kannattaa tehdä, jotta ennustettu ratakatko voidaan välttää. Kaikkia ratakatkoja ei kuitenkaan voida ikinä estää, sillä osa katkoista johtuu siitä yksinkertaisesta syystä että kone tai prosessin osa vaatii oikeasti huoltoa esim. koneen telojen pesua tai vaihtoa.

Avustava tekoäly, joka ymmärtää ihmisen puhetta on vielä ns. proof-of-concept tasolla. Avustava ”Valmet Expert”-avatar saadaan vastaamaan kysymyksiin ja sen tietämyskanta on vielä suhteellisen rajattu. Rajoitteena on vielä ns. monitaitoisen (multi-skill) tekoälyn tietämyksen rakentaminen.

4 Tulevaisuuden näkymät

Nämä ensimmäiset tekoälyyn pohjautuvat ratkaisut ovat avaamassa automaatiolle täyden uusia mahdollisuuksia ja mielenkiintoisen evoluution aikaa, kun useita tehtaita ja erilaisia analytiikka sovelluksia tullaan toteuttamaan tekoälypohjaisesti. Tekoälyn kouluttaminen ja opetusdatan päivittäminen ovat tällä hetkellä ihmisen vastuulla. Tärkeää tässä kehityksessä on pitää ihminen mukana, jolloin tekoälyn tekemät mallit voidaan varmentaa ja samoin päätöksen tekeminen on edelleen ihmisellä. Väärin koulutettu tekoäly tekee vääriä ehdotuksia ja muuttunut ympäristö, johon koulutusdata ei saa tarvittavaa tarkkuutta ei voi säätää prosessia. Siksi ihminen tarvitaan tekemään ja vastaamaan varsinaisesta prosessin ohjaamisesta ja erilaisista huoltotoimenpiteistä laitoksissa.

Viitteet

[1] The next generation of AI assistants in enterprise https://www.oreilly.com/ideas/the-next-generation-of-ai-assistants-in-enterprise2007, 2018

[2] The Rise of a New Generation of AI Avatars https://singularityhub.com/2019/01/15/the-rise-of-a-new-generation-of-ai-avatars/#sm.001t70u7m14uvfsmsph1g9qp6wolg

Extended Abstracts
ISBN 978-952-5183-56-6

Timo Korvola*, Jari Lappalainen, Jukka K. Nurminen

Simulation-based optimization in the cloud

Keywords: optimization, cloud computing, dynamic simulation, genetic algorithm

***Corresponding Author: Timo Korvola:** VTT, E-mail: Timo.Korvola@vtt.fi
Jari Lappalainen: VTT, E-mail: Jari.Lappalainen@vtt.fi
Jukka K. Nurminen: University of Helsinki, E-mail: Jukka.K.Nurminen@helsinki.fi

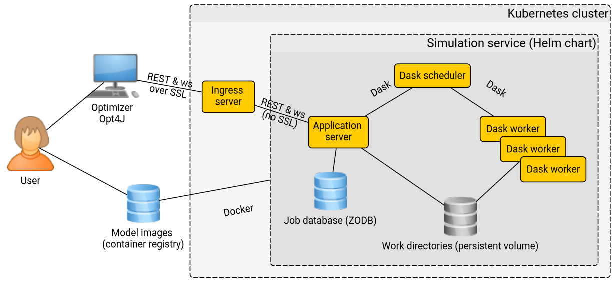


Figure 1. Architecture of the optimization framework.

1 Background

A proper dynamic simulation model provides a tool for simultaneously evaluating process and control design. This is especially valuable for engineering complex industrial processes. While various modelling methodologies have already gained a lot of attention, effective means to exploit the developed models are equally crucial for increasing the use of simulation-aided engineering, and deserves more attention. This research is specially focusing at complex maritime problems involving energy systems and operative aspects [1, 2].

2 Aims

Our objective is to use dynamic simulators out of the box without significant model reformulation, harness cloud resources for simulation-based optimization and facilitate the work flow by developing a framework capable of coping with their complexity and exploiting their scalability.

3 Materials and methods

A schematic view of the optimization framework is presented in Figure 1. An optimizer executes dynamic system simulations to evaluate solution candidates. In such simulation-based optimization, the simulations are usually the dominant computational workload. Our framework provides parallel execution of these simulations in the cloud. This benefits optimization methods that are able to exploit parallel evaluation; we use a genetic algorithm [3], which can evaluate each generation of solution candidates in parallel.

In our framework the simulations are actually executed by a distributed simulation service. The optimizer posts simulation jobs to the service and retrieves results via a REST and WebSocket interface. Such a strict interface allows the optimizer and the simulation service to run on different hosts. It also allows them to be implemented in different languages: currently we use Opt4J [4], a Java-based open source optimization framework, whereas the simulation service is written in Python. The simulation service makes use of several open source libraries and frameworks: Flask for the web service, Dask for managing distributed computation and ZODB for data storage.

For cloud deployment the simulation server is packaged in a Docker image along with the simulator and whatever model data is required. It can then be installed in a Kubernetes cluster with Helm. It is possible to have multiple instances of the simulation service in the same cluster; each instance is specific to a particular model. An ingress server provides them with a common access point and handles security. The optimizer may execute in the cloud or locally on the user's computer. Its computational load is minimal but a reliable network connection to the simulation service is necessary.

4 Results

The framework has been implemented and initial tests have been conducted with a simple Matlab-based model, which was compiled into a Linux executable with the Matlab Compiler. It was then packaged with the simu-

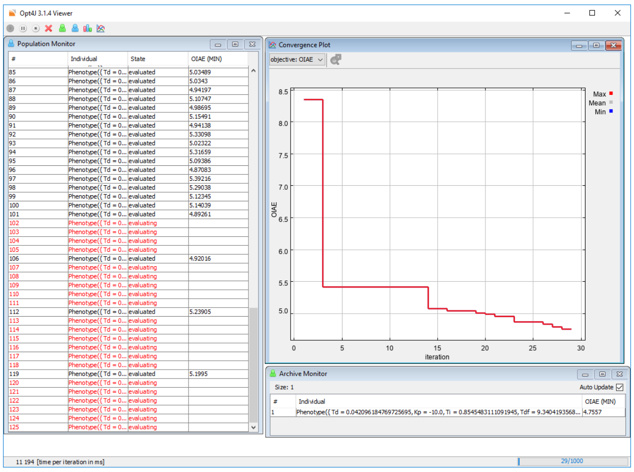


Figure 2. The Opt4J graphical user interface. The graph shows the best objective value by each generation.

lation server and the required Matlab runtime, and deployed to an Azure Kubernetes Service (AKS) instance. The optimizer was executed locally, allowing us to monitor progress with the graphical interface provided by Opt4J (Figure 2).

We initially hoped to run the simulation service on Azure Container Instances (ACI), without managing virtual machines. Virtual Kubelet would dispatch our containers from AKS to ACI. This technology turned out to have significant restrictions and reliability problems. Eventually we had to settle for regular AKS nodes, i.e., virtual machines. That seemed to work fairly reliably but requires scaling the cluster to an appropriate number of nodes before the optimization run and scaling it down to a minimal size afterwards (to avoid paying for unused capacity).

5 Future work

Our test model was so simple that the simulation effort largely consisted of starting the Matlab runtime. The next step is to work with large-scale dynamic simulators. The models origin from different simulation platforms, including Apros and Matlab/Simulink. As the main results so far, we are sharing our experiences on the platform implementation and its performance. A more comprehensive report is presented in [5].

In the later phase of the project, we continue with industrial simulation cases. We want to find out the type and scope of optimization problems that best fit this approach. We also investigate which optimization algorithms promote the optimization with the framework, and how they should be tuned and modified to deliver the best performance in the cloud environment.

References

[1] Lepistö V, Lappalainen J, Sillanpää K, Ahtila P. Dynamic process simulation promotes energy efficient ship design. *Ocean Engineering*. 2016;111:43–55. URL http://www.sciencedirect.com/science/article/pii/S0029801815005909

[2] Zou G, Kinnunen A, Tervo K, Elg M, Tammi K, Kovanen P. Modeling ship energy flow with multi-domain simulation. In: *27th CIMAC World Congress*. Shanghai. 2013; .

[3] Deb K, Pratap A, Agarwal S, Meyarivan T. A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE transactions on evolutionary computation*. 2002;6(2):182–197.

[4] Lukasiewycz M, Glaß M, Reimann F, Teich J. Opt4J - A Modular Framework for Meta-heuristic Optimization. In: *Proceedings of the Genetic and Evolutionary Computing Conference (GECCO 2011)*. Dublin, Ireland. 2011; pp. 1723–1730.

[5] Lappalainen J, Korvola T, Nurminen JK. Cloud-based framework for simulation-based optimization of ship energy systems. In: *Proceedings of MOSES2019, the 2nd international conference on modelling and optimisation of ship energy systems*. Glasgow, UK. 2019; In press.

Acknowledgements

This work belongs to the Task 2.3 in the INTENS research project, jointly funded by Business Finland's Arctic Seas program and the INTENS consortium (Wärtsilä Finland Oy, NAPA Oy, Meyer Turku Oy, Dinex Ecocat Oy, Deltamarin Oy, Vahterus Oy, Protacon Technologies Oy, Parker Hannifin Manufacturing Finland Oy, JTK Power Oy, 3D Studio Blomberg Ab, Jeppo Biogas Ab, Visorc Oy, Tallink Silja Oy, NLC Ferry Ab Oy, Aalto University, Lappeenranta University of Technology, University of Vaasa, Åbo Akademi University and VTT Technical Research Centre of Finland Ltd), which are gratefully acknowledged.

The authors would like to thank Zsolt Homorodi at VTT for assistance with cloud technology.

Lauri Saurus, Lauri Haapanen, Olli Luukkainen

Advanced Process Control With Redundant DCS Communication using OPC UA

Abstract: This paper describes how redundant communication can be established between Advanced Process Control (APC) application and Distributed Control System (DCS) using OPC UA communication protocol.

Keywords: OPC UA, Digitalization, Process Control, Automation, Redundancy

Lauri Saurus: Neste Engineering Solutions Oy, lauri.saurus@neste.com

Lauri Haapanen: Neste Engineering Solutions, lauri.haapanen@neste.com

Olli Luukkainen: Neste Engineering Solutions, olli.luukkainen@neste.com

Extended abstract. Typically communication between APC and DCS is not critical for safe operating of the process and hence communication is without redundancy. Nature of APC is such that if communication between APC and DCS is lost, normally the plant operators can still control the process of the plant. The Consequences of communication breaks are normally economic costs due to process optimization problems. Economic costs may be significant and also the operators trust towards APC may decrease and benefits of using APC diminish. However communication breaks between APC and DCS seldom lead to plant downtime or hazards to people and environment. In addition, redundant communication increases the availability of APC because communication application and operating system updates can be installed to DCS OPC Servers without APC downtime.

The solution presented in this paper bases on OPC UA which is successor to common OPC Classic standards. OPC UA has many benefits over OPC Classic main benefits being platform independent, cyber security features and firewall friendliness. OPC UA is firewall-friendly because only single TCP port opening is normally needed to establish OPC UA communication between server and client residing in different sides of provided by different vendor. OPC UA is international standard and has IEC standard code IEC 62541. At the moment OPC UA has already specification how to implement the redundancy of server and client side in an OPC UA standard conforming way.

The solution presented in this paper is partly based on mechanisms presented in the OPC UA specification. DCS OPC UA server redundancy is based on two parallel OPC UA servers provided by the DCS vendor. Both of these OPC UA servers provide the same OPC UA address space making it possible to access same DCS positions. DCS OPC UA servers do not provide transparent redundancy so the switch over logic is built on the APC server which implements both OPC UA server and OPC UA client. OPC UA client connection is established to each redundant DCS OPC UA server from the APC server. All communications to and from DCS is done using these client connections. The actual data flow is implemented using proprietary OPC UA information model from the APC vendor which defines a variable type that can be connected from APC side to DCS variable using OPC UA client connections which were described earlier. Instances of aforementioned variable type are called communication variables. Communication variable can be defined to monitor the same DCS variable using separate client connections to redundant DCS OPC UA server. In practice the configuration is done by defining primary and secondary source node for the communication variable. Communication variable handles the communication redundancy itself by automatically switching to use another client connection if communication loss is detected with the active connection. This way communication loss is transparent to the APC client software that is monitoring the communication variable. It is also possible to manually switch communication between primary and secondary OPC UA server. Results from the redundant communication between APC and DCS are very promising and it was noted that already in the commissioning phase where frequent changes and updates are needed both in DCS and APC side the redundant communication has provided smoother an faster workflow.

Tomi Lahti*, Lauri Saurus

OPC UA with Publish/Subscribe is now ready to apply for IOT on the process industry

Keywords: OPC UA, IoT, Edge, Publish/Subscribe, PubSub

***Corresponding Author: Tomi Lahti**, Neste Engineering Solutions Oy, E-mail: tomi.lahti@neste.com

Co-author: Lauri Saurus, Neste Engineering Solutions Oy, E-mail: lauri.saurus@neste.com

1 Introduction

Recent technological advances in areas of IoT and data analytics have been massive. As new possibilities are introduced, business requirements for technology are evolving and changing continuously. This has caused process industry companies to hesitate and delay their IoT investment decisions, even if the need for data-extensive applications like predictive maintenance, intelligent real-time analytics, decision-making support, machine learning (ML) and artificial intelligence (AI) is huge. New approaches for implementing industrial IoT solutions have thus been very much in demand.

It has been possible for a while to secure the existing investments when starting to extend data collection systems by taking into account a few fundamental factors: relying to standards when integrating different systems, ensuring supplier independence and noticing strong existence of Industry 4.0 and hence compatibility with related technologies, such as OPC UA. IoT solutions supporting PubSub and Time Sensitive Networking (TSN) are latest part of its reference architecture. Real-life process industries have various use cases that can be economically solved with OPC UA PubSub based IoT solutions.

2 OPC UA with PubSub

Industry 4.0 endorsed OPC UA is likely the best approach for ensuring extensible secure data transfer between plants, edge solutions, and cloud environment. OPC UA has standard data modeling for different purposes and equipment as well as common companion specifications for compatibility between different vendors. Furthermore, it utilizes familiar and established data communication standards. Together with IoT and Edge device remote management and control, OPC UA plays a key role in ensuring system security, integrity and business continuity. As the standard OPC UA, also PubSub works with multiple transport and message protocols. For OPC UA PubSub MQTT with JSON encoding as well as UDP with binary encoding will be available, and selection can expand in the future. Metadata associated with the message provides context which allows the subscribers to properly interpret the message and allow the publishers to report changes to their configurations.

Latest progress in OPC UA offers a compelling solution for connecting applications within the IoT. OPC UA has generic and neutral architecture with separated information model layer, communication models and protocol bindings. 2018 released PubSub enables further adoption of OPC UA at the deepest levels of the field where controllers, sensors, and embedded devices typically require optimized, low power and low-latency communications on local networks. New bindings to standards like TSN and protocols like AMQP and MQTT together with PubSub message model makes it very attractive for IoT systems which requires distributed locations, easy and fast extendability and connectivity and reliable manageability.

As PubSub is especially suitable for IoT and Cloud environments, it's essential that information security is at maximum level. PubSub security key mechanism uses web based standards as OAuth2 for federated identity mechanism. With OPC UA PubSub only applications authorized by the operators will be able to view or modify the data by the end-to-end security no matter how many intermediaries are required to deliver the data. That makes OPC UA with PubSub optimal choice for industrial IoT use cases.

3 IoT PubSub Use Cases

Most important use cases for process industry differ depending on whether studying greenfield or brownfield applications. Similarly, restrictions and limitations vary whether we are implementing new solution from scratch or revamping existing processes or machinery. However the main principles for developing the technological solution are the same.

Easiest and most cost-effective way to implement or modernize distant process asset tracking is to transfer the data wirelessly directly to a cloud service via Industry 4.0 standard OPC UA communications. Instead of using unprotected legacy communication protocols across a Wide Area Network, OPC UA PubSub -based IoT with edge solutions offer modern communication techniques (such as MQTT) which are designed for secure, easily expendable and efficient network communications.

Benefits are crisp also on factory floor level, where controllers, sensors, and embedded devices typically require optimized, low power, and low-latency communications. For example measurements from field which have traditionally been collected daily by workers physically reading the value form meters can be securely and economically feasible way be connected to production information system for real time tracking and analytics purposes.

PubSub enables especially cloud-based use cases as virtually unlimited number of edge data sources, such as intelligent sensors, can supply data securely to internet-based data hubs and applications over public wide-area networks. That makes possible tele monitoring of decentralized assets like tanks and vessels economically with standard devices equipped with suitable sensors for the respective need, for example tracking of vessel fill up and basic analysis of its current content. That is important information for example supply chain optimization for many new circular economy use cases where raw material needs to be collected from small streams.

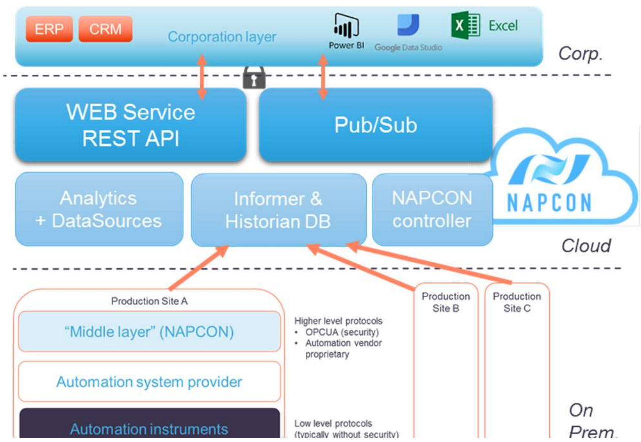


Figure 1. Illustrative picture how NAPCON {1} Understand –products can be used for process information collection from various production DCS and IoT sources to cloud corporation analytics utilizing common cloud platforms. All connectivity between sites and NAPCON Cloud is done via OPC UA.

Currently continually extending data analytics and predictive maintenance needs are increasingly breeding calculation capability demand and moving intelligence from cloud environments to the edge; i.e. near to the source of data and real-world functions. Cloud and Edge solutions boost platform independency but also set strict requirements for information security. To fulfill these needs IoT solutions must be easily extendible and easy to operate and maintain. Now OPC UA with PubSub support offers the most exiting standard set for solutions for these. Time to execute IoT for process industry is now!

References

[1] napconsuite.com

Henri Pettinen, Marko Elo

Utilizing multifunctional display computer as a local gateway in industrial IoT use cases

Corresponding authors: Henri Pettinen: CrossControl Oy, email: henri.pettinen@crosscontrol.com

Marko Elo: CrossControl Oy, email: marko.elo@crosscontrol.com

Keywords: diesel engines, modelling, mean value modelling

Extended abstract. The Industry 4.0 paradigm emphasizes the increased level of automation and data exchange in manufacturing technologies. Hence, industrial companies have to deal with vast amounts of data gathered from the production. Usually it is not practical to send all the measured data outside the local premises for further processing. Onboard processing, temporary storing, and appropriate forwarding of the data are key operations to be handled by an industrial gateway.

CrossControl produces computers for industrial use, with integrated displays. These display computers run individually tailored Linux distributions, optimized by the image footprint and runtime performance. Most common use case for such display computers are in heavy industrial vehicles, with connectivity to the onboard vehicle control bus. By utilizing a dedicated connectivity module, the onboard display can have a wireless connection as well, for on-site device and backoffice connectivity.

This conference paper for Automaatiopäivät23 introduces key parts of the Productive4.0 project which addresses the general theme of Industry 4.0. The paper discusses the use cases of machine and fleet management offered as an industrial Software as a Service (SaaS). The pilot implementation of CrossControl's gateway device is presented with the focus on the software stack, information flow architecture and the graphical user interface. Moreover, applying Service Oriented Architecture (SOA) by means of Arrowhead framework on gateway and edge level is also discussed.

The data flow and the software components deployed for the display computer in both Productive4.0 use cases is outlined in Figure 1. The display computer runs Node.js based runtime and has its own local database up and running. In addition, it is capable of converting HTTP messages to MQTT protocol and distribute those messages to interested MQTT clients, as dispatched by the Mosquitto broker running on the display. Storing data to the database and the message conversion are both offered as a service. The Arrowhead framework gives a standardized way to apply SOA in industrial domain. The implementation allows the full set of Arrowhead services, meaning any kind of devices, to consume the offered services. The display computer is also itself an Arrowhead service consumer as it connects to a bigger database located in the cloud.

The finalization of Arrowhead services at the gateway is in progress, for full implementation of the functionality depicted in Figure 1. This pilot implementation provides a proof-of-concept for deploying a multifunctional device both as an industrial gateway and as a human machine interface, in an Arrowhead-compliant IoT environment.

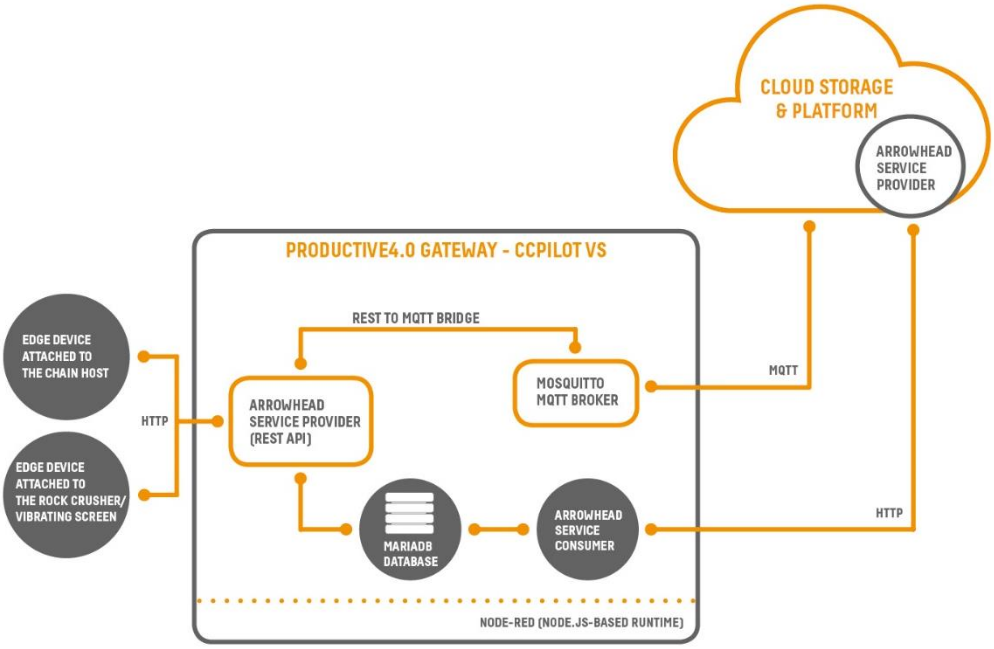


Figure 1. Data flow in Productive4.0 use cases and gateway device's software and technology stack.

ISBN 978-952-5183-56-6

Jukka Koskinen*, Petri Tikka, Hannu Tanner

Industrial IoT applications

*Corresponding Author: Jukka Koskinen, VTT
Technical Research Centre of Finland Ltd, Kaitoväylä 1, FI-90571 Oulu, Finland
E-mail:jukka.koskinen@vtt.fi

Co-authors: Petri Tikka, Hannu Tanner, VTT
Technical Research Centre of Finland Ltd, Kaitoväylä 1, FI-90571 Oulu, Finland
E-mail: {petri.tikka|hannu.tanner}@vtt.fi

Extended abstract. Cloud and edge computing platforms offer new possibilities for data analytics applications. Microsofts's Azure and Siemens Mindsphere are examples of commercial cloud computing platforms that offer wide possibilities for application development and deployment in the cloud especially in big data storage, analysis and visualization. Edge computing platforms and 5G technologies offer possibilities for instance real-time data streaming, analytics, and visualization in the edge of networks

Fiware is an open source platform, which offers components for analyzing and visualization of data from IoT sources. Orion Context Broker component and NGSI information model are the core of Fiware. Orion Context Broker (OCB) provides a NGSI API. Context Broker publishes context information from entities (virtual real-world objects). Entitles can be IoT sensors or application components etc. Context Broker publish context information to context consumers. It supports two-way communication.

Especially SMEs can benefit from Fiware due to open source approach and ease of deployment of the components. Fiware has a strong European background and is favored by the European Union in many projects funded by EU.

VTT has implemented advanced edge computing applications. In this paper, we present three oriented applications from industrial robotic, intralogistics and smart water management domains. They utilize Fiware components.

Jukka Pulkkinen, Igor Trotskii

Data Strategy in Service Development: Case Study for a Facility Management Service Company Utilizing IoT

Jukka Pulkkinen: Häme Univeristy of Applied Science, E-mail: jukka.pulkkinen@hamk.fi

Igor Trotskii: Häme Univeristy of Applied Science, E-mail: igor.trotskii@hamk.fi

Keywords: digital servitization, service design, facility management services, data management, lean service development

Extended abstract. Digital servitization is a key context for the application of data management, analytics and machine learning in service value creation, thereby contributing to improve competitive position. The recent technology development in the area of Internet of Things and cloud computing provides numerous opportunities for digital servitization, and on the other side, a new approach for service design is needed to utilize these opportunities properly. This paper is a case study, which aims to apply the data strategy framework in service design for facility management services in order to ensure the fulfillment of business requirements. The data strategy framework consists of two phases: from the business requirements to work process and from data to actions. This paper demonstrates the usefulness of a data strategy framework for the development of the facility management service having different types of requirements to manage and analyze the data to reach original business requirements. The main contribution of this paper is to demonstrate how the digital servitization can improve the competitive position of the company by a proper service design using data strategy framework.

Pulkkinen [1] presented the general data strategy framework. The data strategy consists of two phases:

- Phase 1: from business requirements to work process
- Phase 2: from data to actions

Phase 1 pays a lot of attention to knowledge that is needed to fulfill the business objectives and how this knowledge is utilized in work processes. This knowledge creates the basis for the data-driven service operation; on the other side, the knowledge needs to be directly connected to the business objectives. This phase consists of three steps that are presented in Figure 1:

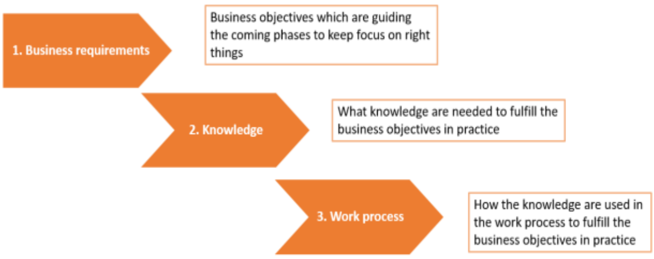


Figure 1. Three-step model in data strategy framework create knowledge, starting from business objective and ending with work process. Slightly modified from source [1].

Phase 2 focuses more on technical implementation and restrictions to implement data-driven service operation in practice. Therefore, a lot of attention is paid to data availability and data quality and how to turn data into a positive user experience by using automatic controls, analytics, and machine learning. Phase 2 consists of three phases presented in Figure 2:

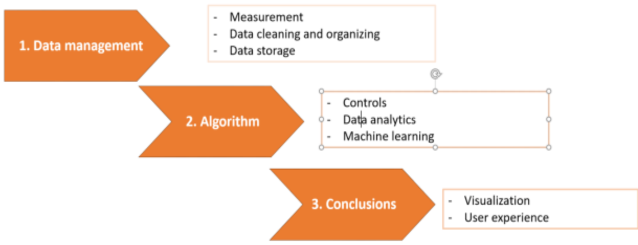


Figure 2. Three-step model in data strategy framework, from data to conclusion. Slightly modified from source [1].

The case study is conducted for facility management services, where the personnel are responsible for operating the building maintenance of multiple buildings owned by their customers. The data management process is applied to the maintenance operation of a building. Actually, the facility management services market is changing in Finland; currently, the market is divided between private and public companies, and there is a trend to move toward private own companies. The winners in the new changing market are the players who can manage their service operation most effectively; therefore, utilizing data for efficiency improvement purposes is a critical success factor. On the other side, the buildings have a lot of data, which could be used to improve the service operation. Naturally, this has not been optimally used yet due to the new technology.

ISBN 978-952-5183-56-6

The research was based on action research with the facility management service providers in a changing market. The facility management service provider has a strategy of sustainable growth in the long term, which requires improving their competitive position in their market. The competitive position improvement is created by utilizing the data in their service operation to reduce the heating and maintenance costs and to positively affect repair needs. The result of the study is that the selected data strategy framework was applicable in the area of the facility management services. The facility management service provider has different areas to improve the competitive position, as mentioned above, and they result in very different data-driven services. However, the framework was applicable to all these areas, emphasizing the strength of the data strategy framework to be applicable in different environments.

Mika Liukkonen, Philip O'Leary, Yrjö Hiltunen*

Quality control of silicon wafers by spatial analysis of wafer maps

Keywords: Quality control, wafer map, independent component analysis, spatial analysis, silicon wafer

*Corresponding Author: Yrjö Hiltunen: University of Eastern Finland, P.O. Box 1627, FIN–70211 Kuopio, Finland, E-mail: yrjo.hiltunen@uef.fi

Philip O'Leary: Murata Electronics Oy, Vantaa, Finland

Mika Liukkonen: University Of Eastern Finland, Kuopio, Finland

1 Background

A wafer map is a pattern of smaller units called cells organized in a two dimensional matrix, or coordinate system. Usually these cells, or chips, represent the final products manufactured from those wafers, such as integrated circuits or sensors. Typically, a wafer map is used for presenting a failure pattern consisting of defected and functional cells of a silicon wafer in a two-dimensional matrix consisting of binary values. Some typical examples of simple failure patterns on wafer maps, based on the examples shown in [1], [2], [3], and [4], are presented in Figure 1.

Yield improvement is a critical issue in the development of electronics manufacturing technology, and facilitating the diagnosis of occurred defects is an important part of this process. Spatial failure patterns presented on wafer maps provide a possible way of searching for the causes of unexpected process variation. In ideal conditions, wafer maps may provide vital guidance in defect diagnosis, making it possible to rapidly determine the potential root causes of defects by identifying patterns [1]. There are a few approaches that are typical in the analysis of spatially clustered wafer maps. Different neural network and clustering algorithms form the foundation of these.

Independent component analysis (ICA) is a statistical method that has been successfully applied to a variety of problems in signal processing [5]. ICA is a method for extracting underlying, fundamental factors or components from multivariate statistical data. It is designed so that it searches for components that are both statistically independent and non-Gaussian [5], which makes it a special method.

2 Aims

The purpose of this study is to find out if it is possible to group wafer maps associated with cell-specific data to enable further actions such as the search for the root causes of bad quality.

3 Materials and methods

3.1. Data

Following the guidelines for typical failure patterns shown in [6], [7], data for this study were artificially generated by creating both systematically occurring defect patterns and random defects and adding these data to a spatial arrangement of cells that is typical for sensor manufacturing. To study the effect of random errors on the extraction of systematically occurring failure patterns, two separate data sets containing 700 samples were constructed, the latter of which was contaminated by random failures (0.5% of cells).

3.2. Independent component analysis

It is assumed here that there are n observed signals (i.e., failure types), FS_1, FS_2, . . ., FS_n in the data, which are linear combinations of *m* independent components, IC_1, IC_2, . . ., IC_m. The equation for IC_i can be written as:

$$FS_i = a_{i1}IC_1 + a_{i2}IC_2 + \cdots + a_{im}IC_m = \sum_{j=1}^{m} a_{ij}IC_j$$

where i = 1, 2, . . ., n and the a_{ij} are real coefficients (contributions of *IC*s). The independent components, IC_j, and also the corresponding coefficients, a_{ij}, are unknown.

The statistical model in Eq. (1) is called the independent component analysis model [5]. The ICA model is a generative model that describes how the observed data are generated by a process of mixing the components IC_j. Both IC_j and a_{ij} need to be estimated using the observed data. The starting point for ICA is the assumption that the components IC_j are statistically independent, which can be concluded from non-gaussianity [5].

4 Results

Here, a fixed-point algorithm (Fast-ICA) was used as an implementation of ICA [5]. The analysis was performed using the Fast-ICA toolbox under the Matlab software platform (Mathworks, Natick, MA, USA). The independent components using the data contaminated by 0.5% of random failures can be seen in Figure 2. It can be seen that the set of extracted components follows quite nicely the set of patterns created artificially.

The independent components using the data contaminated by 0.5% of random failures can be seen in Figure 2. It can be seen that the set of extracted components follows quite nicely the set of patterns created artificially.

5 Conclusions

Based on the results it can be concluded that the data analysis by ICA method allows for decomposition of independent, systematically occurring failure patterns from wafer map data. This new information can be used for guiding further study and may lead to more efficient extraction of root causes for quality problems.

References

[1] Hsu C.Y., Clustering Ensemble for Identifying Defective Wafer Bin Map in Semiconductor Manufacturing, Mathematical Problems in Engineering, 2015, Article ID 707358.

[2] Hsu S.C. and Chien C.F., Hybrid data mining approach for pattern extraction from wafer bin map to improve yield in semiconductor manufacturing, International Journal of Production Economics, 2007, 107, 88-103.

[3] Wang C.H., Recognition of semiconductor defect patterns using spatial filtering and spectral clustering, Expert Systems with Applications, 2008, 34, 1914-1923.

[4] Liu C.W. and Chien C.F., An intelligent system for wafer bin map defect diagnosis: An empirical study for semiconductor manufacturing, Engineering Applications of Artificial Intelligence, 2013, 26, 1479-1486.

[5] Hyvärinen A., Karhunen J., and Oja E., Independent Component Analysis, New York, John Wiley & Sons, 2001.

[6] Stapper C.H., LSI yield modeling and process monitoring, IBM Journal of Research and Development, 1976, 20, 228-234.

[7] Taam W. and Hamada M., Detecting spatial effects from factorial experiments: an application from integrated-circuit manufacturing, Technometrics, 1993, 35, 149-160.

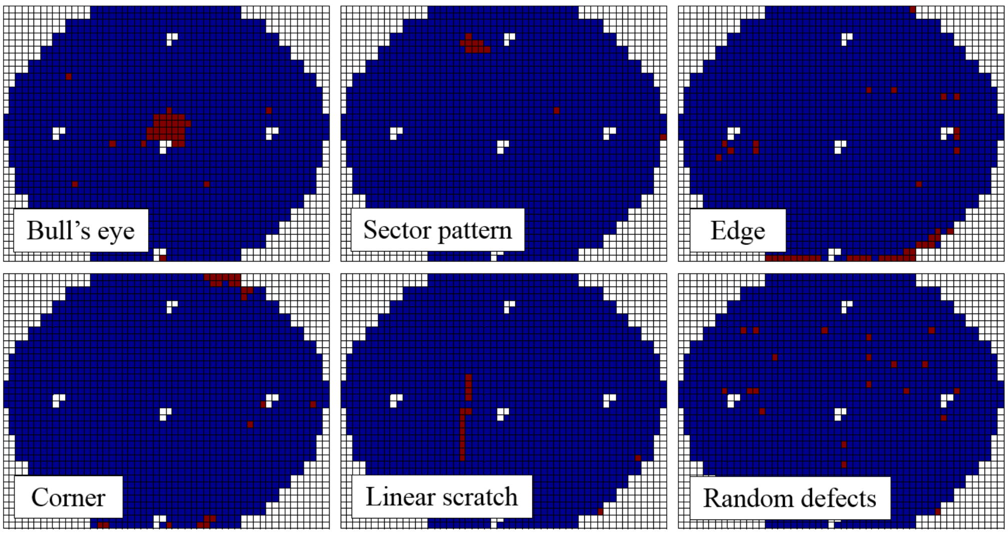


Figure 1: Examples of some typical failure patterns on wafer maps according to literature.

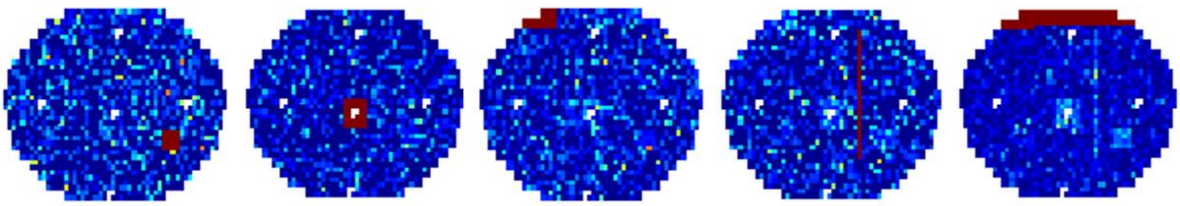


Figure 2: Independent components using the data contaminated by 0.5% of random failures.

Veli-Pekka Pyrhonen*, **Matti Vilkko**

Improving tracking performance of composite nonlinear feedback controllers via new reset and hold feature of nonlinear functions

Extended abstract. Composite nonlinear feedback (CNF) is relatively well-known control design methodology that attempts to achieve simultaneous fast command following and robustness under limited control authority. The CNF methodology produces feedback controllers that consists of parallel-connected linear and nonlinear parts, which are designed as follows. First, the linear part is designed by placing the dominant pair of the closed-loop poles with small damping ratio, which would result in a step response having short rise time but large overshoot. Then, the nonlinear part is designed such that the damping ratio of the dominant pair smoothly increases, when the control error gradually diminishes. Because of such mechanism, the step response of the closed-loop system maintains short rise time, while the overshoot tendency caused by the linear part is eliminated. Overshoot is eliminated, because CNF controllers are able to use significant amount of control at the late stage of the transient response, which eventually shortens the settling time of closed-loop systems. This is the key property of all CNF controllers, which makes CNF methodology feasible for many control applications requiring fast and precise command following.

The nonlinear part of a CNF controller is capable of moving the closed-loop poles to some desired locations in the left half complex plane, which can be specified by the designer. The automatic relocation is accomplished through the choice of a suitable nonlinear function and its careful tuning. In literature, several nonlinear functions have been proposed that have their own pros and cons. Furthermore, an additional scaling parameter for nonlinear functions has been proposed, which is used to make CNF controller more robust to variations in step magnitudes. Such revision is important because many proposed functions are tuned for fixed-size reference inputs. Hence, the tuning parameter values of the nonlinear function may need to be saved for various step sizes to ensure satisfactory transient performance under large operation range of input commands.

However, the proposed nonlinear functions and their revisions work best e.g., in single step experiments, because they are parameterized such that appropriate scaling is obtained when the step experiment is performed. Despite of scaling, the nonlinear functions may not work well, if single step reference is replaced by step sequence references or staircase functions with varying magnitudes. The reason for performance degradation is the invariable initial condition of the controlled output within the scaling parameter. That is, when the reference input is changed, the initial condition remains fixed, which means that the scaling parameter is indeed inherently reset, but the reset value has always an offset.

In this paper, new reset and hold feature is introduced for the scaling parameter such that satisfactory command following is enabled when step sequences are used as reference inputs. The new reset and hold feature is simple in nature: the initial condition of the controlled output is reset to the current measured value of the controlled output whenever the target step reference changes in value at some time instant, while it is kept at the previously set value otherwise. It should be noted that the proposed feature can be applied to other forms of commonly-used nonlinear functions within CNF controllers. The simulation and experimental results of this paper show that the closed-loop control systems designed using the refinements of this paper provide better tracking performance both in steady-state and during transients compared with the control systems without them.

Keywords: control applications, constrained control, linear systems, nonlinear control, servo systems

***Veli-Pekka Pyrhonen:** Tampere University, Tampere, Finland, e-mail: veli-pekka.pyrhonen@tuni.fi

Matti Vilkko: Tampere University, Tampere, Finland, e-mail: matti.vilkko@tuni.fi

Petri Kannisto*, David Hästbacka*, Kari Rainio, Jussi Leinonen, Matias Alarotu, Tiina Pajula, Jouni Savolainen, Matti Vilkko

Plant-wide communication architecture enabling online life cycle assessment

Keywords: process control, information systems, systems integration, online LCA

*Corresponding Author: Petri Kannisto: Tampere University, E-mail: petri.kannisto@tuni.fi

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

Kari Rainio: VTT Technical Research Centre of Finland, E-mail: kari.rainio@vtt.fi

Jussi Leinonen: Outotec Finland Oyj, E-mail: jussi.leinonen@outotec.com

Matias Alarotu: VTT Technical Research Centre of Finland, E-mail: matias.alarotu@vtt.fi

Tiina Pajula: VTT Technical Research Centre of Finland, E-mail: tiina.pajula@vtt.fi

Jouni Savolainen: VTT Technical Research Centre of Finland, E-mail: jouni.savolainen@vtt.fi

Matti Vilkko: Tampere University, E-mail: matti.vilkko@tuni.fi

Extended abstract. Industrial processes can be very energy-intensive and consume resources during the production of essential materials and goods. Many of these processes are large-scale and may include distributed production steps. The suboptimal control of these processes can significantly increase the use of resources and energy as well as environmental impacts.

The plant-wide control of large processes can be difficult. Process control decisions at geographically distributed subunits and plants may contradict with the global optimum if the necessary information is not available. Furthermore, the impact of local decisions to the overall process is not always clear. This calls for plant-wide control strategies on the coordinating supervisory level. In order to improve such monitoring and control methods, new information exchange practices and integration architectures are required.

Integration of information and control systems in production is challenging both from a scalability and interoperability point of view. Most integrations still rely on point-to-point connections, i.e., systems directly requesting information and services or setting new operating set points. Although the production systems are rather stable, the development of new control procedures is laborious due to the number of necessary integrations for accessing the distributed data. This may also cause performance issues for some systems providing data for these advanced control applications spanning several production units. The integration of external constraints, such as logistics or resource costs, to the control optimisation further increases the necessary effort.

With information systems from different decades, vendor-specific interface implementations and application-specific data structures, the integration is further complicated. Despite successful technologies, such as OPC UA, the use of the agreed information models has not yet been established to the point of plug-and-play connectivity. Commonly agreed information models are required as well as adaptation layers connecting incompatible interfaces and legacy systems.

The Horizon2020 funded COCOP project (Coordinating Optimisation of Complex Industrial Processes) aims to enable plant-wide monitoring and control by using the model-based, predictive, coordinating optimisation concept in integration with automation systems. For the control, the intention is to decompose the entire optimisation problem into sub-problems. The concept relies on the fact that truly large systems typically have some definite structure arising from a linking of independent subunits. This structure can be utilised while decomposing the control problem.

An integration and communication architecture has been developed that supports this control approach in a scalable and interoperable manner. The COCOP communication architecture is based on the concept of a message bus as a broker for data and events. This scalable broker acts as a dataflow hub onto which data is sent from information producers and from which information consumers subscribe to process the data. Still, data can even be delivered "on request", which is desirable for historical data.

The communication principle promotes event-driven information exchange, therefore facilitating the development of applications that react timely to production-related events. To improve interoperability, standards-based message structures have been chosen and composed to form the basis of data semantics for process measurements and events.

To support development, a software development kit (SDK) has been implemented. This SDK guides and facilitates the integration of existing systems. Using the SDK, it is easy to create adapters conforming to the agreed messaging semantics. Still, integration to the standards-based communication protocols is possible even without the SDK.

In this paper, we demonstrate the use of the COCOP architecture with an Online LCA case. LCA or Life Cycle Assessment is a standardized (ISO 14040-44: 2006) methodology to assess the environmental impacts throughout the life cycle of a product or service. Traditionally, this has been conducted on a yearly time resolution with averaged data. In contrast, Online LCA uses real-time data that is available in the control systems, thus providing real-time environmental decision support to plant operators and managers. The case process is a distillation process for water-ethanol mixture located at TUT's teaching laboratory. The Online LCA model is integrated to the control system via OPC UA and AMQP (Advanced Message Queueing Protocol), and the LCA results are visualized in Outotec ACT (Figure 1). AMQP is suitable for large data volumes, thus enabling even data-driven solutions, such as machine learning, in future tasks.

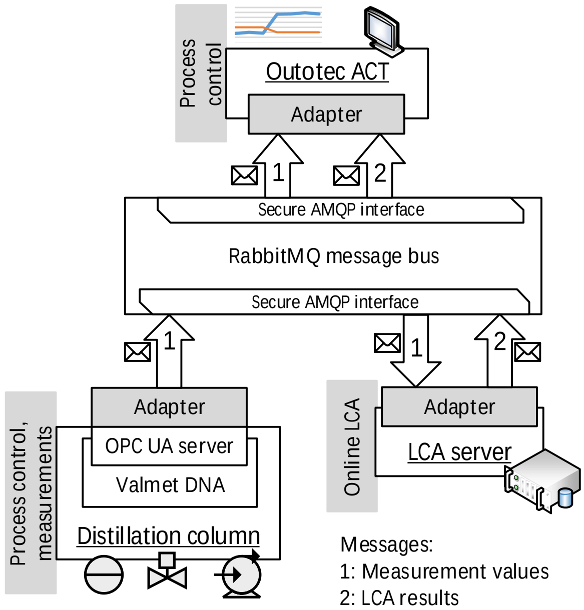


Figure 1. The implementation of the online LCA utilising COCOP communication architecture.

Hannu Rummukainen*, Jukka K. Nurminen

Reinforcement learning for economic lot scheduling

Abstract: We investigated how to apply deep reinforcement learning to discrete-event production control on a stochastic single-machine production scheduling case. We modified the proximal policy optimization (PPO) algorithm for a discrete event model in continuous time, and implemented two state-value approximation methods and control policies, a linear model and a two-layer neural network. Compared to earlier published results on the same case, we improved the average cost rate by 2 %, and moreover, our control policy is entirely learned and is not based on any explicit control heuristics.

Keywords: reinforcement learning, production control, stochastic economic lot scheduling

*Corresponding Author: Hannu Rummukainen: VTT, E-mail: hannu.rummukainen@vtt.fi

Second Author: VTT (currently University of Helsinki), E-mail: jukka.k.nurminen@helsinki.fi

1 Background

Reinforcement learning holds the promise of automatically learning optimal control by trial and error without knowing the system structure. However, applying the approach to systems with multi-dimensional observation spaces is often challenging, and practical applications are rare. Following recent successes in applying deep reinforcement learning to games, we take another look on reinforcement learning as a method for discrete production control.

2 Aims

Our aim is to investigate how to apply a state-of-the-art deep reinforcement learning method in a production control application, what kind of challenges there are, and whether modern methods can improve on earlier results achieved by reinforcement learning.

3 Materials and methods

We performed experiments on a relatively simple stochastic scheduling problem based on research literature. The problem involves scheduling the production of multiple products on a single machine with stochastic demand. Switching the machine from one product to another is both slow and costly, and there are additional costs for holding products in stock, and for unsatisfied customer orders queued in backlog. Although simple, the model is quite challenging to solve, and no closed-form solution is known. In practice production is often controlled by heuristics such as a so-called *base-stock policy*, in which each product is manufactured until its stock level reaches a fixed base-stock level, and then the machine is switched to the next product in a fixed sequence.

We applied an open source implementation of the proximal policy optimization (PPO) algorithm of Schulman et al. [1]. As the lot scheduling model is a discrete event model in continuous time, we modified the PPO algorithm to apply continuous-time discounting. We implemented two different state-value approximation models and stochastic control policies: in the first model, the state-value approximation and the log-probability of an action are linear functions of the observed system state, and in the second model, we use a two-layer neural network.

4 Results

We compared our approach to two base-stock control policies that were published earlier for the same case study: the first policy was a base-stock policy derived by infinitesimal perturbation analysis in [2], and the second policy was a combination of lot-sizing by a base-stock policy and product choice by reinforcement learning [3]. Our model based on a neural network produced a 9 % better average cost rate than the base-stock policy of [2], and a 2 % better average cost rate than the best known earlier solution in [3]. More importantly, our reinforcement learning solution is more general than either of the earlier approaches, since our method is not restricted to policies with pre-specified base-stock parameters, but learns a general policy for every control decision.

Finding the best reinforcement learning policy required a lot of experimentation with different approximation functions and algorithm control parameters, and even then the algorithm required very long training runs to converge. We conclude that reinforcement learning is still best suited to research problems where no satisfactory control policy is known.

References

[1] Schulman, J., Wolski, F., Dhariwal, P., Radford, A., Klimov, O., Proximal policy optimization algorithms, In: 5th International Conference on Learning Representations, 2017

[2] Anupindi, R., Tayur, S., Managing stochastic multiproduct systems: model, measures, and analysis, Oper. Res., 1998, 46, S98–S111

[3] Paternina-Arboleda, C.D., Das, T.K., A multi-agent reinforcement learning approach to obtaining dynamic control policies for stochastic lot scheduling problem, Simul. Model. Pract. Th., 2005, 13, 389–406

Hannu Rummukainen*, Jukka K. Nurminen, Timo Syrjänen, Jukka-Pekka Numminen

Optimization of Facility Layout on the Basis of Example Solutions

Abstract: Designing the layout of a manufacturing facility is a complex multi-disciplinary effort. Instead of explicitly modelling all relevant layout rules, we have investigated an alternative approach for a decision support system: We apply machine learning on examples of well-designed layouts, in order to combine implicit expert knowledge with an explicit layout optimization model. We tested the concept on artificial test data, and the initial results are promising.

Keywords: optimization, facility layout problem, machine learning, constraint programming

*Corresponding Author: Hannu Rummukainen: VTT, E-mail: hannu.rummukainen@vtt.fi

Second Author: VTT (currently University of Helsinki), E-mail: jukka.k.nurminen@helsinki.fi

1 Background

To design the layout of process components in a manufacturing facility, the designer has to consider the construction, operation and maintenance of the facility and all its subsystems, as well as relevant rules and regulations. Due to the complexity of the problem, automated optimization of facility layout has not reached the status of a practical design tool. In research literature, practical design rules have been modelled as explicit constraints, which can be laborious to specify, or left as the responsibility of expert designers in an interactive optimization approach.

2 Aims

We investigated the feasibility of machine learning of design rules from examples of expert-designed layouts. The aim is that learning-based optimization uses example layouts of old facilities to provide reasonable layout proposals for a new facility, without requiring the user to set too many input parameters.

3 Materials and methods

We have developed a probabilistic machine learning model that can be used to evaluate the similarity of a proposed layout to example layouts. We use a model of geometric similarity based on kernel density estimation, which can be derived from a small number (on the order of 10) of example layouts. We combine the probabilistic similarity model with an optimization model that minimizes connection distance (pipe length) between components. The optimization model is based on constraint programming. The connection distance and similarity measure are treated as separate objectives in a multi-objective optimization setting: by weighting the objectives we can choose a different trade-off between the objectives, and provide alternative layout proposals for the user.

To apply the method in practice, the layouts of existing facilities must be available in machine-readable form, and reduced to the most significant components and their connections. A common classification must be defined for the components in the example layouts, and the components of the new facility: e.g. large/small tanks, pumps, and other machines. For the new facility, the user must specify the required components, their dimensions and their connections, and the locations of the building walls. Once cost coefficients are given for the connection lengths, the system then automatically produces layouts that present different trade-offs between minimizing connection cost, and following layout rules similar to the example layouts.

4 Results

We have implemented the similarity model and the layout optimization model, and tested them on artificial test data. Our initial tests indicate that the concept works, and we can successfully trade off similarity to examples and the connection distance objective.

Due to the use of a relatively simple probabilistic model, there is random variation in the learning results especially when the connection structure of the example layouts differs from the new facility. Nevertheless, our combination of machine learning and optimization presents a promising alternative to traditional model-based optimization, which would require much more explicit modelling work to produce layouts similar to those designed by experts.

Kurt-Erik Häggblom*

Data-based experiment design to maximize information for MIMO system identification

Keywords: system identification, multivariable system, ill-conditioned system, experiment design, data-based design

***Corresponding Author: Kurt-Erik Häggblom:** Faculty of Science and Engineering, Åbo Akademi University, Turku, Finland, E-mail: khaggblo@abo.fi

Extended abstract. A problem in the identification of multiple-input multiple-output (MIMO) systems is that the system outputs in an identification experiment may be strongly correlated if the inputs are perturbed by uncorrelated signals, as is standard practice [1]. Such a correlation reduces identifiability.

In principal component analysis (PCA), the maximum amount of information is extracted from a data matrix X into a number of components less than the number of variables in X. The component data vectors (score vectors) are norm-bounded linear combinations of the X columns with maximum sample variance and no sample correlation between component vectors (they are orthogonal). In line with PCA, the aim of the input design proposed in this contribution is to maximize the information content of the outputs by producing uncorrelated outputs with sample variances at some maximum desired level.

The author has previously presented a model-based input design method to obtain uncorrelated outputs with specified variances [2–4]. In this contribution, a purely data-based input design method is proposed. Naturally, this is preferable from a practical point of view. The data are obtained from one or several preliminary experiments with the system to be identified. In the case of one experiment, it can be a standard MIMO experiment with uncorrelated inputs, but better data for the design is usually obtained by performing experiments with one input at a time.

Let the MIMO system to be identified have n inputs and n outputs with numerical values $u(k)$ and $y(k)$, respectively, at sampling instant k. The dynamics of the system can be described by the model

$$y(k) = G(\mathrm{q})u(k),$$

where $G(\mathrm{q})$ is a matrix of pulse transfer operators defined through the shift operator q. The input design does not require knowledge of this model and it is not required that a model of this form is identified; it is mainly introduced to facilitate the description below.

The input design is based on the use of an n-dimensional perturbation signal $\xi(k)$. Usually, this signal is a random binary sequence (RBS), a pseudo-random binary sequence (PRBS), or a multi-sinusoidal signal (MSS). The individual signals $\xi_i(k)$, $i = 1, \dots, n$, should preferably be uncorrelated with one another as in a standard identification experiment. The input design is done by deriving a linear combination

$$u(k) = T\xi(k)$$

that will produce uncorrelated outputs $y(k)$ with desired variances. This design is based on data obtained from the previously mentioned experiment(s).

For an $n \times n$ system, the output covariance matrix is defined by $n(n+1)/2$ parameters. This means that the same number of independent elements of T is sufficient to determine the output covariance matrix, which in the case of uncorrelated outputs with variance 1 is the identity matrix. This can be achieved by a triangular or symmetric/skew-symmetric T matrix (including row and column permutations), for example. If a full T matrix is used, some additional property besides output correlation can be optimized. It is possible, for example, to minimize input or output peak values, or the input crest factor. Such options are illustrated by the use of an ill-conditioned distillation column model.

References

[1] Ljung, L., System Identification: Theory for the User, 2nd ed, Prentice Hall, Upper Saddle River, NJ., 1999

[2] Häggblom, K. E., Experiment designs for identification of multivariable dynamic systems, Automaatio XXII Seminar, March 23-24, 2017, Vaasa, 9 pp

[3] Häggblom, K. E., A new optimization-based approach to experiment design for dynamic MIMO identification, IFAC-PapersOnLine, 2017, 50-1, 7321–7326, DOI: 10.1016/j.ifacol.2017.08.1473

[4] Häggblom, K. E., Easy ways to design inputs to obtain uncorrelated outputs in MIMO system identification, IFAC-PapersOnLine, 2018, 51-15, 227–232, DOI: 10.1016/j.ifacol.2018.09.139

Esko K. Juuso

Expertise and uncertainty processing with fuzzy systems for automation

Keywords: fuzzy set systems, fuzzy arithmetic, domain expertise, uncertainty

***Corresponding Author: Esko K. Juuso:** Control Engineering, Environmental and Chemical Engineering, University of Oulu, E-mail: esko.juuso@oulu.fi

1. Background and aims

Domain expertise and uncertainty processing need to be integrated in automation solutions which rely on data analytics and artificial intelligence. In many cases, the result might look very good but is precisely wrong if the solution is based on overfitting or important facts or data are not taken into account. The systems should have a level for assessing what is approximately correct.

Statistical models are in various ways used in data-driven modelling and rule-based systems form the basis for handling expertise. Case-based systems, neural computing and machine learning expand the solutions to large-scale problems. Complexity of the systems can be reduced by using nonlinear scaling for variables.

The solutions are aimed to bring the expertise and uncertainty processing to integral parts of the Cyber Physical Systems (CPS) [1].

This paper analyses alternatives of fuzzy extensions of parametric systems where the meanings of variables, different types of fuzzy and parametric systems are used as building blocks. Fuzzy systems provide tools for uncertainty processing and integrating domain expertise.

2. Materials and methods

Parametric statistical models based on multivariable linear regression are the basic solution for the interactions. Response surface methods include more complex interactions. Linear solutions can be extended to case-based systems by using linear parameter varying (LPV) models. Neural networks can further extend the complexity of nonlinear interactions considerably through machine learning.

Fuzzy systems are based on rules, relations and local models, which include fuzzy numbers and labels represented by membership functions (MFs). The uncertain facts are processed by calculations with the degrees of membership.

Nonlinear scaling improves the numerical calculations in these systems. The nonlinear effects are as much as possible taken into account with the nonlinear scaling [2, 3].

3. Solution

The solution is based on three stages: (1) Meanings of the variables, (2) Uncertainty of the variables and model coefficients are represented by fuzzy numbers, and (3) Both lines of system development, statistical and fuzzy, are efficiently extended to nonlinear applications by modifying the meanings of the variable levels. The linear models and rulebases focus here on the directions of interactions.

Uncertainties of the inputs are taken into account by using fuzzy numbers as the inputs of different fuzzy systems which are combined embedded parametric systems. These solutions are extended by nonlinear scaling functions (NSFs) which also make them easier to combine and tune.

When fuzzy rule-based systems are represented with scaled fuzzy inputs, membership functions (MFs) can be developed from NSFs and existing MFs can be used in developing NSFs. Fuzzy set systems and linguistic equation systems are consistent within the limits of detail. In recursive analysis, both meanings and interactions on all levels can be tuned together with genetic algorithms.

4. Applications

In applications, the modular overall system consists of similar subsystems, which are normally used. Uncertainty is included with extensions to with the fuzzy extensions.

- **Case-based models** can utilize fuzzy working point models or LPV model solutions where the LE submodels can have fuzzy inputs and or fuzzy coefficients [4, 5].

- **Intelligent control solutions** use combined fuzzy and LE models in intelligent analyzers which provide informative indices for the control and decision making. In the solar thermal power plant, the focus is in the working control where all the actions are integrated [6].
- **Diagnostic solutions** are fuzzy systems where condition monitoring and process data are combined with performance indices in intelligent analyzers. Symptoms are versatile facts, including labels, inequalities and trends. [7] Natural language interface is important in diagnostics [8].

The compact fuzzy modules can be developed for specific tasks which are combined within Cyber Physical Systems (CPS) [1]. The fuzzy extensions provide a feasible way for the sensitivity analysis of the solution.

5. Conclusions

Expertise and uncertainty processing can be efficiently integrated by compact nonlinear scaling which simplifies statistical, fuzzy and neural solutions. In large-scale parametric systems, fuzzy systems are used for balancing contradictory information, non-numeric expertise and operating areas.

References

1. E.K. Juuso. Smart adaptive big data analysis with advanced deep learning. Open Engineering, 8(1):403–416, 2018.
2. E. K. Juuso. Integration of intelligent systems in development of smart adaptive systems. International Journal of Approximate Reasoning, 35(3):307–337, 2004.
3. E. Juuso and S. Lahdelma. Intelligent scaling of features in fault diagnosis. In 7th International Conference on Condition Monitoring and Machinery Failure Prevention Technologies, CM 2010 - MFPT 2010, 22-24 June 2010, Stratford-upon-Avon, UK, volume 2, pages 1358–1372, 2010.
4. E. K. Juuso. Development of multiple linguistic equation models with Takagi-Sugeno type fuzzy models. In Proceedings of 2009 IFSA World Congress/ 2009 EUSFLAT Conference, July 20-24, 2009, Lisboa, Portugal, pages 1779–1784. IFSA-EUSFLAT, 2009.
5. Esko Juuso. Intelligent multimodel simulation in decomposed systems. In Proceedings of The 59th Conference on Simulation and Modelling (SIMS 59), 26-28 September 2018, Oslo Metropolitan University, Norway, number 153, pages 308–315. Linköping University Electronic Press, Linköpings universitet, 2018.
6. E.K. Juuso. Fuzzy adaptation of intelligent control for solar thermal power plants. 30th European Modeling and Simulation Symposium, EMSS 2018, pages 343–348, 2018.
7. E. K. Juuso. Intelligent performance analysis with a natural language interface. Management Systems in Production Engineering, 25(3):168–175, 2017.
8. E. K. Juuso. Informative process monitoring with a natural language interface. In 2016 UKSim-AMSS 18th International Conference on Modelling and Simulation, 6-8 April, 2016, Cambridge, UK, pages 105–110. IEEE Computer Society, 2016.

Francisco J. Gómez*, Matias Alarotu, Gerardo Santillán, Tommi Karhela, Takahiro Kanbe

Online Life Cycle Assessment: Case Vinyl Acetate Monomer Process

Extended Abstract: Life Cycle Assessment (LCA) is a "cradle-to-grave" analysis of the environmental costs associated with a given product [1]. Due to their association with large uncertainties, LCA models are used to predict the direct and indirect environmental impacts associated to the production of a product. They cover the whole life cycle of products, from raw materials acquisition to end use, recycling, or disposal. Such models are commonly used for supporting decisions of policymakers as well as for assessing impacts and costs of any production process.

Online LCA focuses on continuous LCA computation results based on real-time information collected from the equivalent system. This is possible by a direct communication between the model and the physical process. As a result, Key Performance Indicators (KPIs) of the related process can be continuously calculated for assessing environmental impact on the modeled system [2]. Online LCA significantly reduces the time required for gathering the information to support decision-making in product and technology development projects. It increases environmental awareness of process operators, policy makers and other actors involved in decision making.

Industrial process plants, such as chemical plants, could greatly benefit from applying the online LCA for taking short and long-term operation actions that would reduce their environmental impact. In these plants, online LCA systems could be implemented by connecting LCA tools and their models directly to the plant control system by directly embedding LCA models into the automation system of the plant. Thus, reduction of implementation costs, communication overheads and integration effort could be achieved. In this work, this approach is explored by embedding a Functional Mock-up Unit (FMU) of an LCA model into the control system of a Vinyl Acetate Monomer process [3].

The Functional Mock-up Interface (FMI) standard [4] targeted for model exchange and co-simulation of heterogenous models, can be utilized to implement the integration of LCA models. The LCA model, originally developed on the SULCA tool, is exported as an FMU and then embedded into the process control application of the plant, to continuously asses environmental impact of the modelled process, by adjusting the LCA values according to possible changes on the control process. In the paper, the architecture and case study including the description of the process and LCA model will be explained.

Keywords: Life Cycle Assessment, Online LCA, FMI, Vinyl Acetate Monomer, Control System

***Corresponding Author: Francisco J. Gómez:** Semantum Oy, E-mail: francisco.gomez@semantum.fi

Matias Alarotu: VTT, E-mail: matias.alarotu@vtt.fi

Gerardo Santillán: Semantum Oy, E-mail: gerardo.santillan@semantum.fi

Tommi Karhela: Semantum Oy, E-mail: tommi.karhela@semantum.fi

Takahiro Kanbe: Yokogawa Electric Corp, E-mail: Takahiro.Kanbe@jp.yokogawa.com

References

[1] International S. Organization, "ISO 14040:2006 – Environmental Management - Life Cycle Assessment - principles and framework", Technical report, International Organization for Standardization, 2006.

[2] C. Dorn, R. Behrend, D. Giannopoulos, L. Napolano, V. James, A. Herrmann, V. Uhlig, H. Krause, M. Founti, D. Trimis, "A Systematic LCA-enhanced KPI Evaluation towards Sustainable Manufacturing in Industrial Decision-making Processes. A Case Study in Glass and Ceramic Frits Production", Procedia CIRP, Volume 48, 2016, Pages 158-163, doi: https://doi.org/10.1016/j.procir.2016.03.146.

[3] Michael L. Luyben, Björn D. Tyréus, An industrial design/control study for the vinyl acetate monomer process, Computers & Chemical Engineering, Volume 22, Issues 7–8, 1998, Pages 867-877, https://doi.org/10.1016/S0098-1354(98)00030-1.

[4] Functional Mock-up Interface (FMI) Standard, (On-line), Available at: https://fmi-standard.org/

Jaakko Etto, Matti Paaso

Automaatioinsinöörin kompetenssit ja osaamisen oppiminen

Asiasanat: automaatio, etäopetus, etälaboraatio

Kirjoittajat: Jaakko Etto ja Matti Paaso, Lapland University of Applied Science, {jaakko.etto|matti.paaso}@lapinamk.fi

1 Johdanto

Lapin Ammattikorkeakoulussa on sähkö- ja automaatioalan insinöörikoulutuksen opetussuunnitelmat uusittu vuonna 2017 projektiperusteisiksi. Jokaiselle lukukaudelle on määritelty oppimisen keskiönä oleva projekti, joka kokoaa koko lukukauden osaamisen keskeiset osa-alueet projektia tukevien opintojaksojen avulla. Projektien ja opintojaksojen tavoitteet ovat määritelty laadittujen koulutusten yhteisten sekä sähkö- ja automaatioalan kompetenssien perusteella.

Oppimisen tavoitteiden saavuttamisen keskeinen väline ovat oppimisympäristöt. Opetuksen kehittämisen ratkaisevat työpanokset suunnataankin oppimisympäristöjen kehittämiseen ja oppimisympäristöissä oppimistapahtumissa käytettäviin pedagogisten menetelmien toteuttamiseen. Seuraavassa on esitelty projektimuotoisen automaatioinsinöörikoulutuksen sisältöä ja toteutuksen muutosta.

2 Automaatioinsinöörikoulutuksen opetussuunnitelma

Lapin Ammattikorkeakoulussa on automaatioalan insinöörikoulutuksen opetussuunnitelma uusittu useaan kertaan, suurimmat muutokset lienee vuosina 1992, 1997, 2001, 2007 ja 2017.

Lapin ammattikorkeakoulussa päätettiin kahden eri ammattikorkeakoulun Kemi-Tornio ja Rovaniemi yhdistymisen jälkeen saada kaikkien koulutusten pedagogiset ratkaisut samankaltaisiksi. Uusien opetussuunnitelmien laatimisesta vastasivat eri koulutusten avainhenkilöt. Opetussuunnitelman kehitystyön yhteydessä järjestettiin laajat koulutukset mm. projektimuotoisen koulutuksen pedagogisista menetelmistä ja arvioinnin menetelmistä. Samalla perehdyttiin jo käytössä oleviin parhaisiin käytänteisiin.

Opetussuunnitelmatyössä määrättiin opintojen laajuudeksi 5 op ja sen kerrannaiset, kun aikaisemmin automaatioinsinöörikoulutuksen opintojaksot olivat olleet 3 op ja sen kerrannaisia. Jotta uusi OPS2017 ei koostuisi vanhan opetussuunnitelman opintojaksojen yhdistelyistä päätettiin muuttaa myös oppimisen aikataulutusta. Samoin päätettiin, että kaksi ensimmäistä opintovuotta sähkövoima- ja automaatiotekniikan koulutuksessa ovat sisällöltään samoja.

Projekteja ja projektityöskentelyä haluttiin myös opettajien toimesta koulutuksessa lisätä, koska opiskelijat olivat olleet tyytyväisiä projektitöihin ja projekteina toteutettuihin opintojaksoihin jo 20 vuoden ajan. Projektityöt insinöörikoulutuksessa aloitettiin jo 1990-luvun alkupuolella ja niitä kokemusten karttuessa lisättiin ammatillisiin moduuleihin projektityön tai erikoistyön nimellä.

Uuden opetussuunnitelman sisällön laatimisessa keskeinen lähtökohta oli automaatioinsinöörin osaamisen määrittelevät kompetenssit, eli mitä valmistuvan insinöörin tulisi osata. Kompetenssien laadinta tehtiin yhteistyössä teollisuuden kanssa.

Ammattikorkeakoulun uusien opetussuunnitelmien kehittämisessä koulutusten kompetenssit ryhmiteltiin käytännössä kolmeen osioon:

- yhteiset kompetenssit (kaikki alat)
- sähkö- ja automaatioinsinöörien yhteiset (alan yhteiset) kompetenssit
- automaatiotekniikan (alan eriytyvät) kompetenssit

Yhteiset kompetenssit on määritetty kaikille koulutuksille saman sisältöisiksi ollen seuraavilta osa-alueilta:

- oppimisen taidot

– eettinen osaaminen ja vastuullisuus
– työyhteisöosaaminen
– innovaatio-osaaminen
– kansainvälistymisosaaminen.

Sähkö- ja automaatiokoulutuksen yhteiset kompetenssit on määritelty yhteistyössä alueen teollisuuden kanssa ja ovat seuraavat:

– sähkötekninen perusosaaminen
– suunnitteluosaaminen
– sähköturvallisuus ja turvallisuusosaaminen
– yritys- ja liiketoimintaosaaminen
– kiertotalousosaaminen.

Automaatioinsinöörin osaamisalalle määriteltiin lapin ammattikorkeakoulussa kolme omaa kompetenssia:

– automaatiojärjestelmien ja automaation tietotekniikan osaaminen
– prosessien automaatiototeutuksien osaaminen
– kenttäinstrumentoinnin, mittaustekniikan ja säätötekniikan osaaminen.

Ensimmäiset versiot kompetensseista ja niiden sisältömäärittelyistä laadittiin opettajien työryhmissä. Nämä sitten lähetettiin eri yritysten edustajille kommentoitavaksi ja palautetta varten. Saadun palautteen perusteella kompetensseja muokattiin ja korjattiin.

2.3 Automaatiotekniikan kompetenssit

Kompetenssien määrittelyssä oli keskeistä automaatioinsinööriltä vaadittava osaaminen eikä määrittelyä rajattu ammattikorkeakoulun silloisen henkilökunnan ja oppimisympäristöjen perusteella. Määrittely perustui nykyisiin ja tulevaisuuden ennustettuihin osaamistarpeiden kuvaamiseen. Automaatiotekniikan kompetenssit 1, 2 ja 3 on esitetty seuraavissa luetteloissa opiskelijan osaamisen näkökulmasta.

Kompetensseissa määriteltyjen osaamisten saavuttaminen edellyttää monipuolisia oppimisympäristöjä ja osaavia oppimisympäristöjen ja opetuksen kehittäjiä. Se miten hyvin olemme onnistuneet selviää lähitulevaisuudessa kun automaation ammattiopinnot toteutetaan ensimmäistä kertaa uuden opetussuunnitelman mukaisina.

AUTOMAATIOTEKNIIKKA 1/3: AUTOMAATIOJÄRJESTELMIEN JA AUTOMAATION TIETOTEKNIIKAN OSAAMINEN

Tiedän automaatiojärjestelmien aikaisempia ja nykyisin käytössä olevia rakenteita ja toimintoja.
Tunnen ohjelmoitavien logiikoiden ominaisuuksia sekä toteutustapojen ja toiminnan eroja.
Hallitsen automaatiototeutusten määrittelyn ja ohjelmointia.
Tunnen toimilaitteiden ja mittausten väyläratkaisuja ja –liityntöjä.
Tunnen eri kenttäväylien käyttökohteita ja väylien keskeiset ominaisuudet.
Osaan vertailla automaatiojärjestelmien ja ohjelmoitavien logiikoiden ominaisuuksia ja toimintoja sekä tuotantolaitosten että rakennusten tarpeisiin.
Osaan käyttää suunnittelu- ja simulointiohjelmistoja.
Tunnen automaation turvatekniikan.
Tunnen automaatiototeutuksien vaatimuksia: tietoliikenneyhteydet, OPC-serverit, pilvipalvelut, virtuaalitekniikat ja tietoturvallisuus.
Osaan valita ja suunnitella käyttöliittymiä, kuten näytöt ja paneelit.
Tunnen teollisen internetin mahdollisuuksia.

AUTOMAATIOTEKNIIKKA 2/3: PROSESSIEN AUTOMAATIOTOTEUTUKSIEN OSAAMINEN

Tunnen yksikkö- ja kokonaisprosesseja ja niiden toimintoja.
Tiedän lähialueen teollisuuden prosessien toimintoja ja niiden tyypillisiä ohjaus- ja säätötapoja.
Osaan toteuttaa ohjauksia ja säätöjä ohjelmoitavalla logiikalla tai automaatiojärjestelmällä.
Tunnen automaatiojärjestelmän HW- ja SW-suunnitteluvaiheet määrittelyvaiheesta toteutukseen.
Tunnen kenttäinstrumentoinnin ja toimilaitteiden valintaperiaatteita eri sovelluskohteisiin erityisesti lähialueen tuotantoprosesseissa.
Tunnen kenttäinstrumentoinnin, kaapeleiden ja toimilaitteiden tyyppipiirikaaviot, -asennukset ja käytännön asennusratkaisuja.
Tunnen automaation ja ohjausten käyttöönoton, koestustoiminnan ja piiritestauksen.
Osaan automaatiototeutuksen eri vaiheiden dokumentaation tuottamisen.

AUTOMAATIOTEKNIIKKA 3/3: KENTTÄINSTRUMENTOINNIN, MITTAUSTEKNIIKAN JA SÄÄTÖTEKNIIKAN OSAAMINEN Tunnen konventionaalisen takaisinkytketyn säätöpiirin teorian ja käytännön sovelluksia. Osaan suunnitella ja toteuttaa prosessikokeita. Tunnen prosessidynamiikan perusmallit ja PID säätöpiirien viritysmallit. Osaan suunnitella ja toteuttaa mittaus-, säätö-, venttiili- ja moottoripiirin. Osaan valita, mitoittaa ja virittää antureita, lähettimiä ja toimilaitteita. Tunnen kenttäinstrumentoinnin tyyppiasennuskuvat ja piirikaaviot. Osaan valita ja sijoittaa kenttäinstrumentoinnin eri prosesseihin ja toteuttaa näin toimivan mittauksen. Tunnen kenttäinstrumentoinnin kalibroinnin ja laatuseurannan. Osaan säätöventtiilien valinnan ja mitoituksen.

3 Oppimisympäristöt ja pedagogiset ratkaisut

Oppimisympäristöinä käytetään nykyisiä ja tulevia laboratoriotiloja:

- prosessiautomaation vesiprosessit
- automaation valvomotila
- sähkövoimatekniikan laboratorio
- ohjaustekniikan laboratorio
- mittaustekniikan laboratorio
- tuotantoautomaation älypaja.

Pääosa luettelon oppimisympäristöistä on vanhoja pitkään opetuskäytössä olleita, laitteet osin jopa 1980 luvulta. Tilat soveltuvat kuitenkin erinomaisesti perinteisen ja väyläohjatun automaation ja ohjaustekniikan oppimiseen. Automaatiolaitteet ja osin muukin tekniikka on päivitetty jo useita kertoja ammattikorkeakoulutuksen aikana. Kenttäväylien ja internet yhteyksien toteuttaminen aloitettiin 1990 luvulla.

Teollisen internet 4.0 ja IoT toteutus laboratoriotilojen oppimisympäristöissä toteutetaan periaatteessa kahdella eri tavalla. Nykyisten laboratoriotilojen I/O kaapeloitujen ratkaisujen ja väyläohjausten rinnalle on toteutettu ja toteutetaan uusimpia valvomoratkaisuja ja etäopetuksen ratkaisuja. Toisaalta on helpointa toteuttaa täysin uuden tuotantolinjan toteuttamisella. Tällöin vanhat ympäristöt ovat edelleen käytettävissä I/O ja väylätekniikoilla automaation alimpien ja konkreettisten tasojen oppimisessa. Tällainen myös automaation oppimista palveleva tuotantolinja on tarkoitus toteuttaa konetekniikan koulutuksen älypaja hankkeessa.

Älypajahankkeen tuotantolinja sisältää perusautomaation lisäksi MES ja ERP tasojen toiminnot tuote- ja raaka-ainevarastoineen, jolloin koko toimitusketju tulee myös osaksi automaatioinsinöörin koulutusta ja osaamistarpeet voidaan saavuttaa nykypäivän uusimmalla tekniikalla. Teollinen internet 4.0 ja IoT automaation toteutus antaa mahdollisuuden märiteltyjen kompetenssien oppimiseen ja palvelee alueen teollisuuden tarpeita niin konealan kuin automaatioinsinöörien kulutuksessa.

Pedagogisina ratkaisuina ja menetelmiksi on valittu opetussuunnitelmien lähtökohdista johtuen joka lukukausi toteutettavat projektityöt ja niiden aihepiireihin liittyvät opintojaksot. Opintojaksot sisältävät teorialuentoja, tietoiskuja, demonstraatioita, suunnittelutehtäviä ja laboraatioita.

Opintojaksojen laajuudet muuttuivat aikaisemmasta 3 op laajuudesta 5 op laajuuteen. Opettajuus muuttui yhden opettajan omasta opintojaksototeutuksesta tiimiopettajuuteen, jolloin yksittäisen projektin tai opintojakson toteutuksen hoitaa vähintään 2 opettajaa. Tällainen muutos ei ole helppo, koska aikaisemmin opettaja sai itse määrätä miten toteuttaa tavoitteet ja muita ei tarvinnut kuunnella. Uusi opetussuunnitelma vaatii laajempaa opetuksen suunnittelua ja valmistelua, kun omien opetettavien osuuksien lisäksi on huomioita opintojakson tiimiopettajuus sekä projektiopintojakso ja moduulikokonaisuus.

Esimerkki opintokokonaisuudesta on toisen opintovuoden keväällä toteutettava teollisuuden sähköistyksen ja automaation teema, opintomoduuli, joka koostuu 5 op laajuisista opintojaksoista:

- Teollisuuden sähköistys- ja automaatioprojekti
- Teollisuuden sähköistys- ja automaatiotekniikka
- Sähkökäytöt ja automaatio
- Sähkökoneet.

Opintosisältöjä on aiemmin opetettu eri opintojaksoissa useamman lukuvuoden aikana eri opettajien toimesta. Nyt pitää toteuttaa oppimisen kannalta keskeinen projekti ja projektiin on saatava ohjausta projektitoteutuksen lisäksi muissa moduulin opintojaksoissa ja oikeaan aikaan.

4 Kokemuksia opetussuunnitelmasta

4.1 Tiimiopettajuus

Aikaisemmin opettajat opettivat omat 3 op opintojaksonsa oman näkemyksensä mukaisesti. Nyt tiimiopettajuudessa opettajia on useampi samalla opintojaksolla (5op). Tämä ohjaa yhteistyöhön ja yhteistyö mahdollistaa myös opettajien työpanoksen skaalautumisen ja särkymävaran poissalojen suhteen. Huonoimmillaan opettajien keskustelu toteutuksesta ja sisällöistä on jälkijättöistä, jolloin asiakokonaisuudessa voi olla turhia toistoja tai sisällöllisiä puutteita.

4.2 Projektit

Oppimisen keskiössä olevat projektit voivat olla ohjaamisen ja arvioinnin suhteen haasteellisia. Parasta olisi, että opiskelijat ovat projekteissaan samassa tiedontarpeen vaiheessa, jolloin opastus tapahtuisi samanaikaisesti. Osa opastuksesta ja ohjauksesta on aina ryhmäkohtaisesti tapahtuvaa, osa luonnistuu kirjallisilla tai audiovisuaalisilla ohjeistuksilla. Projektien sopivien laajuuksien määrittely etukäteen on osoittautunut haastavaksi. Mieluummin hieman suppea projekti kuin liian laaja, jotta opitaan prosessi ja saadaan laadukasta tuotosta aikaiseksi.

4.3 Oppimistulokset

Automaation oppimistulosten arviointi on vielä hieman vaikeaa, koska automaation ammattiopinnot, ammatilliset moduulit, ovat juuri alkamassa. Arviointi perustuu kahteen eri asiaan: prosessin ja tuotosten arviointiin. Keväällä 2019 ensimmäisen ammatillisen moduulin arviointitulokset selviävät ja niitä voi sitten verrata aikaisemman opetussuunnitelman mukaisiin tuloksiin.

4.4 Monimuotokoulutus

Samaa opetussuunnitelmaa noudatetaan sekä nuorten että aikuisten monimuotokoulutuksessa. Koska lukukausilla on teemat, projektit ja niiden tukiopintojaksot, niin opintojen ajoitusmuutokset monimuodossa eivät ole helppoja toteuttaa. Tämä on aiheuttanut raskaan kuormituksen ensimmäiselle opintovuodelle. Lisäksi monimuotototeutuksessa on vähän kontaktiopetusta, jolloin oppimisympäristöihin tutustuminen ennen laboraatioita ja etäopetusta jää kevyeksi.

Jaakko Etto, Matti Paaso

Automaation etälaboraatioiden ja etäopetuksen kehittäminen

Asiasanat: automaatio, etäopetus, etälaboraatio

Kirjoittajat: Jaakko Etto ja Matti Paaso, Lapland University of Applied Science, {jaakko.etto|matti.paaso}@lapinamk.fi

1 Johdanto

Lapin Ammattikorkeakoulussa on sähkö- ja automaatioalan insinöörikoulutuksen päivä- ja monimuoto- opetuksen opetussuunnitelmat olleet yhtenevät vuodesta 2001 alkaen. Opiskelijoista puolet opiskelee monimuotokoulutuksessa. Monimuoto-opiskelijoilla on nykyisissä toteutuksissa lukukaudessa 3 lyhyttä kontaktijaksoa. Täten opiskeluaika automaatiotekniikan laboratorioissa jää lyhyeksi.

Oppimisen mahdollisuuksien parantamiseksi on kehitetty prosessiautomaation etälaboraatioita yli 20 vuoden ajan. Ensimmäisten etälaboraatioiden tekniset ratkaisut on korvattu uusilla ja samalla etälaboraatioiden piiriin on otettu sähkökäyttöjen ohjaukset. Seuraavassa esitellään etälaboraatioiden merkitystä ja toteutusta Lapin Ammattikorkeakoulun automaatiotekniikan insinöörikoulutuksessa.

2 Oppimisympäristöt ja etälaboraatiot

2.1 Oppimisympäristöt

Lapin Ammattikorkeakoululla ammatillisen osaamisen oppimisympäristöinä useita eri laboratoriotiloja:

- sähkönjakelun ja sähkökoneiden laboratorio
- kiinteistöjen sähköistyksen ja tietoteknisten järjestelmien laboratorio
- ohjaustekniikan laboratorio
- prosessiautomaation prosessitila
- automaatiovalvomotila.

Nämä opetuksen tilaratkaisut ovat monikäyttöisiä ja niissä toteutetaan automaatiotekniikan insinöörikoulutuksen luentoja, tietoiskuja, projektitöitä, harjoitustehtäviä ja käytännön laboratoriotöitä. Pedagogisina menetelminä ovat:

- luennot
- tietoiskut
- demostraatiot
- harjoitus-ja suunnittelutehtävät
- projektityöt
- laboratoriotyöt
- etälaboratoriotyöt.

2.2 Etälaboraatiot

Monimuoto-opetuksessa luennot, tietoiskut ja demonstraatiot sekä tehtävien ohjaus ja palaute toteutetaan etäopetuksena. Nykyisin käytössä ovat Adobe Connect ja Moodle. Laboratoriotöistä osa tehdään kontaktina laboratorioissa ja osa etänä oppijalle parhaiten sopivina ajankohtina tai opettajan opastamina etäopetustilanteissa. Käytännön prosessiautomaatioon tutustuminen ja kytkennät tehdään edelleen laboratorioissa kontaktikerroilla. Etänä tehtäviksi laboraatioiksi on havaittu hyvin soveltuvan useiden eri oppimistehtävien:

- opetusprosessien mittaus- ja säätötekniikka
- opetusprosessien automaatiototeutukset
- sähkömoottorilähtöjen HMI ja ohjauslogiikan ohjelmointi
- sähkömoottorikäyttöjen automaatiototeutukset.

Opiskelijan kannalta aikaan ja paikkaan sitomattomina tehtävät laboratoriotyöt antavat mahdollisuuden opiskella prosessiautomaatiota ja sähkömoottoreiden ohjausta heille sopivina ajankohtina. Kontaktipäivinä on paikan päällä mahdollisuus tarkastella automaation toteutusta sekä etänä toteutettuja ja testattuja automaation ja ohjausten toteutuksia käytännössä.

Sähkökäyttöjen ja teollisuuden moottorilähtöjen keskuslähdöistä osa on varattu etäopetuksen käyttöön ja osa oppimisympäristöissä tapahtuvaan kontaktiopiskeluun. Oppimisympäristöissä opiskelijat liittävät automaatiolaitteen I/O rajapintaan opiskeltavan moottorilähdön ja siihen liittyvät anturit, kytkimet ja merkkivalot ja prosessin.

Nuorten opetus tapahtuu arkipäivisin laboratorioiden oppimisympäristöissä ohjatusti. Nykyisin myös nuorten päiväopetuksessa on kontaktiopetuksen vähennyttyä otettu käyttöön aikaisempaa laajemmin etälaboraatiot. Nuorten koulutuksessa moottorilähtöjen ohjausten opiskelu on voitu toteuttaa kokonaan oppitunneilla ja joskus osin etänä. Opiskelijat eivät ole aina tienneet ohjelmoivansa automaatiojärjestelmiä etäopetuksen menetelmillä.

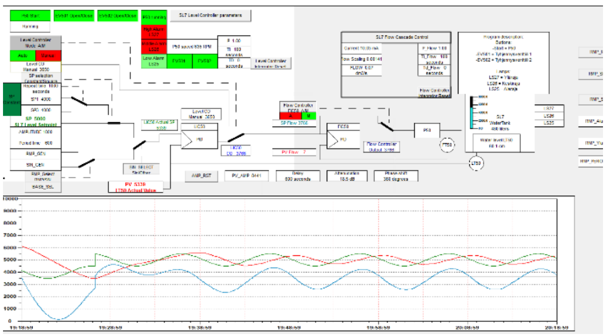
2.3 Esimerkkejä etälaboraatioista

Nykyisissä opetussuunnitelmissa monimuotokoulutuksessa enää vain käytännön kytkennät sekä ohjausten mittausten ja säätöjen oppimisen alkuvaihe toteutetaan lähiopetuksena. Keskuslähtöihin ja ohjauskomponentteihin sekä automaatiopiireihin ja ohjattaviin prosesseihin tutustumisen jälkeen opiskelijat voivat opiskella etänä. Kotoa onnistuu käyttöliittymien ja logiikkaohjelmien ohjelmointi ja sen jälkeen ohjelman toiminnan testaus erilaisilla ajotavoilla eri ohjaus- ja vikatilanteissa.

Etäohjattaviin moottorilähtöihin on lisätty vikatilanteiden ja ohjausten generointi etänä. Tällöin viat ja ohjaustapahtumat välittävät todellisten sähkökeskusten ja kentän komponenttien kautta eikä simulaatioina. Osa moottorilähtöjen ohjauksista ja vioista testataan etäopetuksen ohjatuissa oppimistilanteissa, kun esitellään etälaboraatioiden suorittamisen eri mahdollisuuksia.

Teollisuuden moottorilähdöistä on mahdollista valita ohjattaviksi niin PES kuin MCC moodin moottorilähtöjä suoralla tai suunnanvaihtolähdöllä. Perinteiset I/O ohjatut toteutukset ovat olleet havainnollisia ja erittäin käyttökelpoisia oppimisessa. Teollisuudessa on siirrytty laajalti älykkäisiin moottorilähtöihin ja kenttäväylien käyttöön, joten osa näistäkin moottorilähdöistä (UMC ja Simocode) tullaan ottamaan etälaboraatioiden piiriin.

Kuvassa 1 on esitetty etäopiskelijan automaatioliitynnän esimerkkinäkymä sähkömoottorilähtöä ohjattaessa ja ohjelmoitaessa.



Kuva. 1. Eräs prosessi lähestyy "stationaarista vaihtotilaa" eli siniheräte ja sen vaste. Vihreä on asetusarvo, sininen on toimilaitteen ohjaus ja punainen on mittaussignaali.

Prosessiautomaation ohjaus toteutetaan käytännössä aina etälaboratorioliitynnän kautta. Opetuksen vesiprosessin taajuusmuuttajakäyttöjen, kenttäinstrumentoinnin, toimilaitteiden ja valvomon toiminnan, automaation ohjelmoinnin ja säätöjen toteutuksen oppiminen on siirretty kokonaan etäliittymän avulla toteutettavaksi.

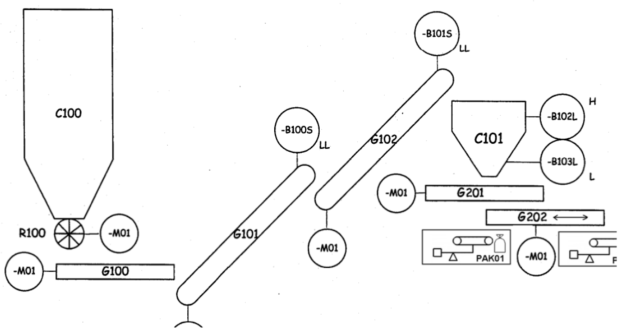
Nuorten opetuksessa tätä liittymää käytetään myös kontaktiopetuksessa. Opetusprosessi palvelee prosessiautomaation mittaus- ja säätötekniikan sekä valvomotoimintojen opiskelussa.

Opetussuunnitelmassa projektityöt ovat oppimisen keskiössä ja niiden toteuttamisen tukena ovat tukiopintojaksot, joissa opiskellaan teoriaa ja käytäntöä, erillisiä laboratorio-opintojaksoja ei enää ole. Esimerkiksi toisen opintovuoden keväällä toteutetaan teollisuuden sähköistyksen ja automaation opintomoduuli, joka koostuu 5 op laajuisista opintojaksoista:

– Teollisuuden sähköistys- ja automaatioprojekti
– Teollisuuden sähköistys- ja automaatiotekniikka
– Sähkömoottorikäytöt ja automaatio
– Sähkökoneet.

Monimuoto-opetuksessa tämän moduulin teollisuuden sähköistyksen ja automaatiotekniikka sekä sähkökäytöt ja automaatio opintojaksojen laboratoriotyöt pääosin ovat etälaboraatioita. Sähkökoneiden opintojakson laboratoriotyöt ovat kontaktiopetuksena vielä tässä vaiheessa oppimisympäristöjen kehitystyötä.

Etälaboraatioissa voi opiskelija toteuttaa yksittäisen moottorilähdön tai laajemman kokonaisuuden automaation. Usein helpointa on aloittaa yksittäisistä moottorikäytöistä ja laajentaa siitä suurempiin kokonaisuuksiin, kuva 2.



Kuva 2. Etäohjattava prosessi

Etälaboraatioiden tekninen toteutus tällä hetkellä perustuu tosibox-tikkuihin ja ABBn automaatiojärjestelmiin. Oppimisympäristöt liitetään ABB automaatiojärjestelmään, ohjattavaan sähkökäyttöön tai osaprosessiin. Opiskelijat rakentavat omalla aikataulullaan automaatiototeutukset sekä testaavat niiden toimintaa eri ajomalleilla, ohjaustavoilla ja vikatilanteilla. Etäohjausten rinnalla on toteutettu reaaliaikainen simulointi Matcad prime 4 ja matlab simulink.

3 Etälaboraatioiden kehittäminen

Saatujen kokemusten perusteella automaation etäopetusta kehitetään lähitulevaisuudessa:

- tarkemmat työohjeet etälaboraatioihin
- kamerat havainnollistamaan todellisten piirien toimintaa
- ajanvarausjärjestelmä
- uusia laitteistoja ja prosesseja etälaboraatioiden piiriin uusille toteutettaville ammatillisille moduuleille

ISBN 978-952-5183-56-6

Tero Hietanen *, Timo Heikkinen, Manne Tervaskanto, Satu Vähänikkilä

Verkottunut yhteistyö automaatiokoulutuksessa

Tiivistelmä: Oululaiset automaatiotekniikan koulutusorganisaatiot kehittävät alueelle uutta keskitettyä digitaalista oppimisympäristöä (DigiAuto-hanke) ja uudenlaista toimintamallia automaatiokoulutukseen (EduAuto-hanke). Mukana ovat kaikki alueen ammatillisen koulutuksen kouluttajat (Oulun ammattikorkeakoulu Oamk, Oulun yliopisto OY, Oulun seudun ammattiopisto OSAO) ja tämä muodostaa uudenlaisen eri kouluttajien välisen toimintaympäristön. Tässä artikkelissa kuvataan opetusympäristöjen kehitystyötä sekä pilotoituja toteutuksia. Pilotoidut toteutukset ovat vähintään kahden eri oppilaitoksen välisiä yhteisprojekteja. Lisäksi tuodaan esille laitteistojen ylläpidon toteutusta sekä yhteisen varausjärjestelmän kehittämistä.

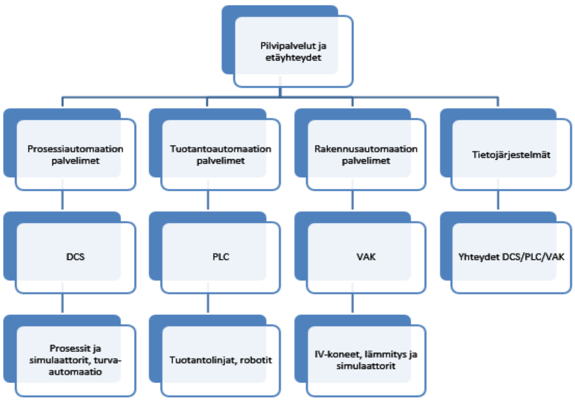
Asiasanat: IoT, koulutus, digitalisaatio

***Tero Hietanen,** Oulun ammattikorkeakoulu, Tero.Hietanen@oamk.fi

Timo Heikkinen, Manne Tervaskanto and Satu Vähänikkilä, Oulun ammattikorkeakoulu, etunimi.sukunimi@oamk.fi

1 Johdanto

Hankkeissa on investoitu uuteen teknologiaan ja uusien yhteistyömuotojen kehittämiseen. Hankittua teknologiaa käytetään prosessiautomaation, tuotantoautomaation, rakennusautomaation sekä teollisuuden tietojärjestelmien kouluttamiseen, kuvan 1 mukaisesti. Yhteisinä tekijöinä ovat IoT, digitalisaatio sekä etäkäytettävyys.



Kuva 1. DigiAuto-hankkeen hankintalinjat.

Prosessiautomaation koulutukseen on hankittu mm. virtualisoidut automaatiojärjestelmien suunnittelu ja simulointityökalut Valmetilta. Tämä pitää sisällään mm. historiatiedon tallennusjärjestelmän moderneine datan analysointi- ja visualisointityökaluineen. Lisäksi järjestelmään kuuluu teollisen mittakaavan mallipreditiivinen säätöjärjestelmä, jolla ohjataan mm. Oamkin pilot-prosessia. Säätötekniikan koulutukseen on hankittu kannettavat miniprosessit, joihin on liitetty prosessiasema sekä tarvittava kenttä-I/O. Oamkin pilot-prosessin kenttälaitteet on modernisoitu sekä liitetty HART- ja Profinet-väyliin.

Tuotantoautomaation tärkeimmät hankinnat ovat Mitsubishin robottijärjestelmä sekä Feston MPS-tuotantolinjasto. Feston järjestelmässä tuotantotieto kulkee RFID-tekniikalla erilliseltä MES-järjestelmältä ohjaavalle logiikalle. Lisäksi laitteiston käynnissäpidossa hyödynnetään AR-teknologiaa (Augmented Reality). Keskeisimpänä rakennusautomaation hankintana on laivakonttiin rakennettu energia- ja LVI-tekniikkaa sisältävä hybridijärjestelmä. Laitteisto sisältää mm. aurinkopaneelit ja -keräimet, tuuliturbiinin, ilmalämpöpumpun, akuston sekä lämminvesivaraajan. Laitteistoa ohjataan Fidelixin automaatiojärjestelmällä. Laitteiston etäohjauksessa hyödynnetään Tosibox-tekniikkaa.

Yhteisten resurssien ylläpidon ja varausten sekä koulutusmateriaalin yhteiskäytön mahdollistavan toiminnanohjausjärjestelmän on toteuttanut ALMA Consulting Oy. Hankkeessa toteutettava oppilaitosten yhteinen automaatioympäristö laajentaa jo olemassa olevaa koulutusyhteistyötä sekä tarjoaa monipuolisen ja laaja-alaisen ympäristön erilaisille automaatioalan tutkimus- ja yrityshankkeille.

2 Toiminnanohjausjärjestelmän kehitys

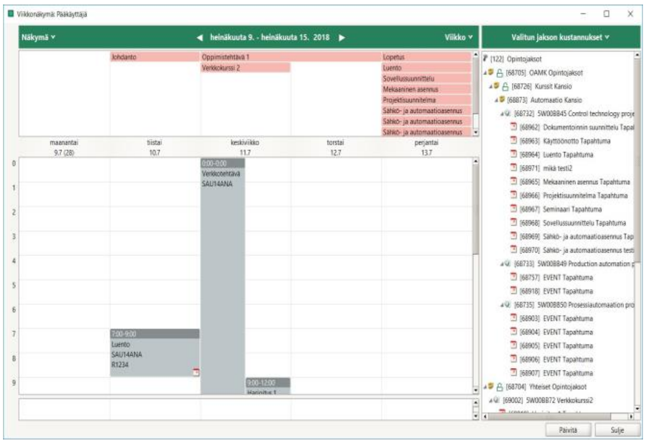
Uusien hajautettujen koulutusresurssien sekä yhteisen koulutuksen toteuttaminen vaatii myös yhteisen toiminnanohjauksen kehittämistä. Hankkeessa automaatioteknologia sekä tilojen ja oppilasryhmien hallinta on viety ALMA-toiminnanohjausjärjestelmään.

ISBN 978-952-5183-56-6

ALMA® on ollut markkinoilla vuodesta 1986 ja tuotemerkki on rekisteröity 13 maassa. Sen takana on ALMA Consulting Oy, joka kehittää, markkinoi, toimittaa ja ylläpitää ALMA® suunnittelu-, teknisen tiedon ja tapahtumien sekä kunnossapidon hallintajärjestelmää sekä siihen liittyviä palveluita. /1/

EduALMA-koulutuksen toiminnanohjausjärjestelmää voidaan hyödyntää mm. opetuksen suunnittelussa, oppimateriaalin hallinnassa, oppimisympäristöjen ja tilojen varauksissa, oppilasryhmien hallinnassa, automaatiolaitteistojen ylläpidossa sekä opintojaksojen toteutuksessa.

Kuvassa 2 on esimerkki opiskelijan viikko-kalenterinäkymästä. Viikoittainen opetus on koottu opintojaksojen tapahtumista.

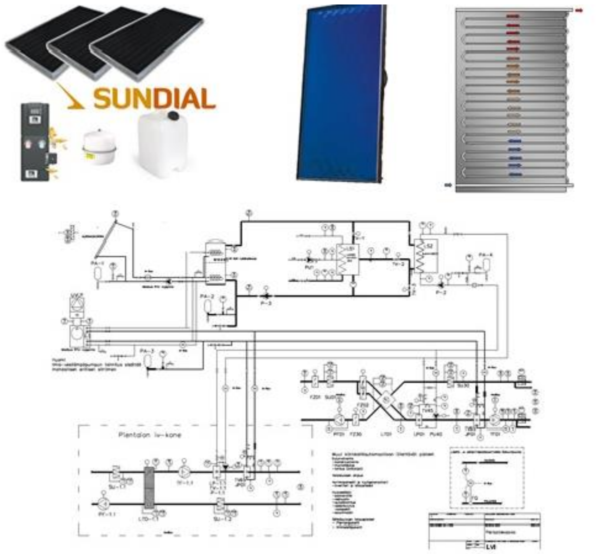


Kuva 2. ”Lukujärjestys” 7-päivää kalenterissa.

3 Rakennusautomaation oppimisympäristöt

Kuvassa 3 on esitetty hybriditekniikkaan perustuva kiinteistöautomaatiojärjestelmä. Lämpö tuotetaan aurinkokeräimillä, ilma-vesilämpöpumpulla sekä sähkövastuksella. Aurinkokeräimillä ja ilmavesilämpöpumpulla tuotettu lämpö ohjataan varaajaan. Varaajassa on lisäksi sähkövastus, joka tarvittaessa tuottaa lisälämpöä varaajaan. Varaajalta lämpö siirretään lämmönjakopaketille, joka lämmittää lämpimän käyttöveden, sekä lämmitykseen tarvittavan veden.

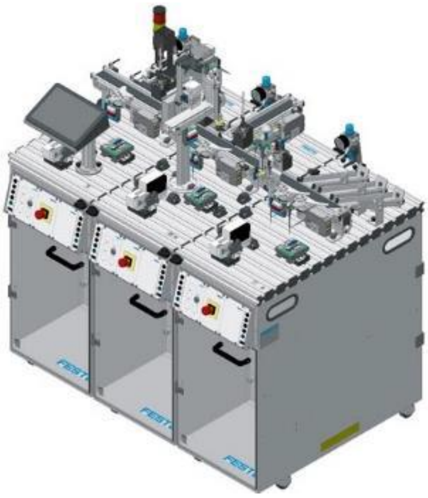
Rakennusautomaation oppimisympäristöä hallitaan Fidelixin-automaatiojärjestelmällä. Lisäksi Fidelix on toimittanut taloteknisten järjestelmien simulointiympäristön. Laitteistoon liittyen opiskelijat ovat tehneet rakennus automaatio-projekteja.



Kuva 3. Rakennusautomaation oppimisympäristön teknologiaa.

4 Tuotanto-automaation oppimisympäristöt

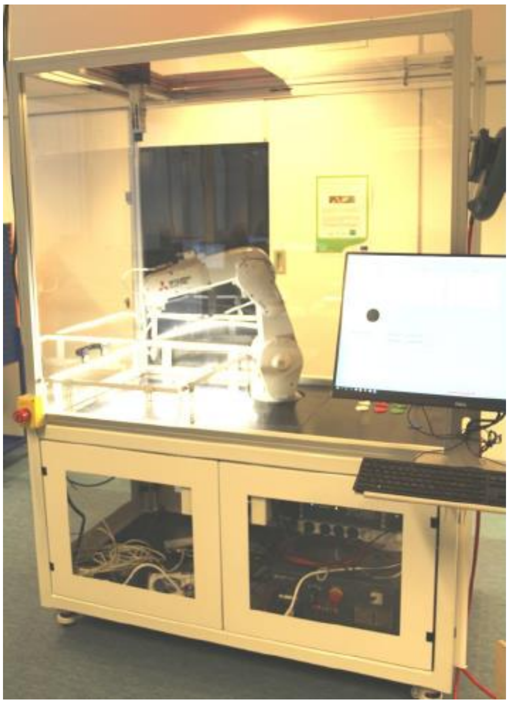
Tuotantoautomaation liitettyjä laitteistoja on käytetty yhteistyössä OSAO ammattiopiston ja OAMK välillä. Tähän opetuskokonaisuuteen sisältyy mm. Feston MPS tuotantolinja, jonka ohjauslogiikkaa voidaan konfiguroida Siemens S7-1500 logiikalla, kuva 4.



Kuva 4. Festo MPS tuotantolinjasto.

Linjasto kattaa myös erillisen MES-palvelimen, jolla voidaan toteuttaa tuotannonohjausjärjestelmä linjastolle RFIDtekniikan avulla. Mielenkiintoinen lisäpiirre on lisätyn todellisuuden (AR – Augmented Reality) hyödyntäminen linjaston käyttöönotossa ja operoinnissa.

Syksyllä 2018 aloitettu ja kevään 2019 jatkuva yhteistyöprojekti tuotantoautomaatioon ja robotiikkaan liittyen OSAO:n ja OAMK:n välillä. Robotiikan opiskelu on aloitettu opettelemalla ohjelmointia RT ToolBox -ohjelmiston avulla ja tekemällä tällä ohjelmalla simulointeja. Tästä on siirrytty ohjelmien testaamiseen robottien avulla. Kevään aikana tarkoituksena on tehdä OSAO:n ja OAMK:n opiskelijoiden yhteistyöprojekteja robotiikkaan ja tuotantoautomaation liittyen. Kuvassa 5 DigiAuto-projektin puitteissa hankittu robotti.



Kuva 5. DigiAuto-hankkeen robottimoduuli.

5 Prosessiautomaation oppimisympäristöt

Uudistetut laitteisto- ja ohjelmistoratkaisut ovat tarkoittaneet myös projektityyppisten kurssien sisältöjen uudistamista ja kehittämistä. Projekteista on osa toteutettu jo kuluneen lukuvuoden aikana oppilaitosten välisinä yhteistyöprojekteina.

Näihin voidaan lukea mm. Automaatiotekniikan erikoistyö –kurssi, jossa OSAO:lla veden kierrätys- ja lämmitysprosessiin on liitetty uusi Valmet SR1-prosessiasema. Asemalle on etäyhteyden päässä olevalla EAS suunnitteluasemalla tehty sovellus- ja käyttöliittymäsuunnittelu sekä sovellustestaus. Ammattikorkeakoulun opiskelijat ovat tehneet prosessiin piirikaaviot Loop Circuit CAD:lla, joiden mukaisesti ammattiopiston opiskelijat ovat kytkeneet mittaus- ja toimilaitteet kiinni prosessiin sekä testanneet kytkentöjen toimivuuden. Tämän jälkeen ammattikorkeakoulun opiskelijoiden tehtävänä on ollut sovellussuunnittelun teko ja järjestelmän käyttöönotto sekä toiminnan raportointi. Projekti on vaatinut eri opiskelijaryhmien tiivistä yhteistyötä.

Teollisen malliprediktiivisen säätimen (MPC) testausta ja simulointia on tehty yhdessä sekä ammattikorkeakoulun että yliopiston opiskelijoiden toimesta. AMK:lla on keskitytty historiatiedonkeruun konfigurointiin ja datan luotettavaan tiedonvälitykseen MPC-palvelimen ja automaatiojärjestelmän välillä. Yliopistolla suurempi painoarvo on ollut MPC:n konfiguroinnissa, monimuuttujasäätöjen simuloinnissa ja järjestelmätestauksessa. MPC-palvelimelle on pääsy etäyhteyden kautta 20 käyttäjälle molemmista oppilaitoksista, joten myös yhtäaikainen työskentely on ollut mahdollista.

Yhteenveto

Laitteistohankinnat mahdollistanut DigiAuto-hanke päättyi vuoden 2018 loppuun. Rakennusautomaation laitteistokokonaisuuden rakentamisessa, käyttöönotossa ja koulutuksissa oli pientä viivettä. Hankintakokonaisuudessa oman pääosin oppilasvoimin tehdyn suunnittelu- ja asennustyön osuus oli suurin. Kehitystyötä jatketaan vielä mm. etäyhteyksien käyttöönoton ja koulutusten osalta. Vastaavasti prosessiautomaation hankintalinjan osalta on eniten yhteisiä kokemuksia projekteista. Opiskelijat ovat ottaneet yhteistyön vastaan myönteisesti ja osallistuminen on ollut aktiivista. Yhteishankkeet antavat hyvän valmennuksen eri tehtäviin liittyvistä työelämärooleista.

Lähdeluettelo

https://www.alma.fi/ 4.2.2019

Extended Abstracts
ISBN 978-952-5183-56-6

Antti Liljaniemi*, **Heikki Paavilainen**

Using Digital Twin Technology in Engineering Education – Course Concept to Explore Benefits and Barriers

Extended abstract: The digital twin technology is one of the main technologies related to the Industry 4.0. Term digital twin is commonly used in industry and scientific community; even so, an exact definition of this concept is under research. The concept of using “twins” leads back to NASA’s Apollo program, where at least two identical space vehicles were built, allowing the engineers to mirror the conditions of the space vehicle during the mission, the vehicle remaining on earth being called the twin. The concept nowadays known as the Digital Twin (DT) was introduced in 2002 by Michael Grieves. DT definitions in prior research emphasize that each system consists of two systems, the physical system and a virtual system that contains all of the information about the physical system. E.g. Siemens uses the following definition: *“A digital twin is a virtual representation of a physical product or process, used to understand and predict the physical counterpart’s performance characteristics. Digital twins are used throughout the product lifecycle to simulate, predict, and optimize the product and production system before investing in physical prototypes and assets.”*

In engineering education it is vital that the curriculums and the contents of the education are kept up-to-date. This designates that the education environments and know-how of the teachers are abreasted as well. With adopting new digital technologies like DT tools we can provide new knowledge for the students, teachers and companies. This can have an impact for the employment of the students and competitiveness of the companies. The main aim of this research was to create a course concept to research digital twin technology in engineering education and to adopt the technology in education. The research aimed as well to explore the benefits and barriers of the DT technology, should it be included into the curriculums, what would be the best way to adopt the technology and to evaluate the maturity level of the technology. The main research method was action research for making the observations, more precisely KJ-technique. The research was planned in three cycles between 2016 and 2018. To support and for additional findings an inquiry was made for the students after the third cycle concerning the digitalization and DT technology. Furthermore statistical data of the DT courses were analyzed and compared with other courses.

The present study confirmed the earlier findings concerning digitalization in engineering education. Digital tools and DT technology can increase motivation for studying, students own responsibility for learning, improve learning and is already sometimes too much emphasized instead of a personal encounter. Compared with other machine automation courses the yield and first time through were at the same level, DT technology did not increase or decrease these key indicators. As a result of this research a ‘digital twin’ course was successfully created to prove the concept. The current setup still has limitations and need to be further developed. When using the tools as a separate design tools the operation was stable, but when ‘digital twins’ were e.g. connected with PLCs many problems were faced with OPC version and other malfunction issues. To use and exploit the created twins and the technology in other courses a virtual mechatronic lab could be created. This would enable the using of the twins in other courses and researching the benefits further.

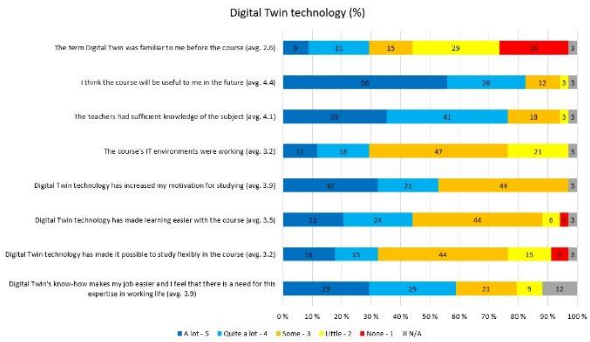


Figure 1. Digitalization inquiry, replies to question Digital Twin technology

Keywords: Digital Twin, Digital Shadow, Industry 4.0, Engineering Education, Virtual Learning Environment

***Corresponding Author: Antti Liljaniemi:** Metropolia University of Applied Sciences, E-mail: antti.liljaniemi@metropolia.fi

Heikki Paavilainen: Metropolia University of Applied Sciences, E-mail: heikki.paavilainen@metropolia.fi

Khoa Dang*, Igor Trotskii

Architecture for Automation System Metrics Collection, Visualization and Data Engineering – HAMK Sheet Metal Center Building Automation Case Study

Extended Abstract: Ever growing building energy consumption requires advanced automation and monitoring solutions in order to improve building energy efficiency. Furthermore, aggregation of building automation data, similarly to industrial scenarios allows for condition monitoring and fault diagnostics of the Heating, Ventilations and Air Conditioning (HVAC) system. For existing buildings, the commissioned SCADA solutions provide historical trends, alarms management and setpoint curve adjustments, which are essential features for facility management personnel. The development in Internet of Things (IoT) and Industry 4.0, as well as software microservices enables higher system integration, data analytics and rich visualization to be integrated into the existing infrastructure. This paper presents the implementation of a technology stack, which can be used as a framework for improving existing and new building automation systems by increasing interconnection and integrating data analytics solutions. The implementation is realized and evaluated for a nearly zero energy building, as a case study.

The proposed stack consists of OPC-UA as industrial communication protocol for efficient machine-to-machine data transmission on the field level, combined with Node-RED with OPC-UA package for simple interconnection between different software interfaces. For transmission from multiple fields and reusability of data, Node-RED also performs packaging and sending data through MQTT to a private broker. Following this on the server side, time series storage and analytics software, represented by InfluxData’s time series platform, are used for data ingress, preprocess and warehousing. Grafana is used for generating dashboards to perform preliminary inspection and production of visualization elements e.g. charts, gauges and metrics overview tables. Grafana also supports exporting CSV files from built elements for further analytics with Python such as feature extraction and anomaly detection, which supports the condition monitoring and condition-based maintenance processes. Finally, Docker is used for deployment and management of all components at their respective level.

Reasons for selection of aforementioned technologies include their open-sourced nature, reproducibility and adaptability. OPC-UA is widely adopted by industrial manufacturers nowadays and could be implemented in existing programs with minimal efforts, allowing for operation data extraction from field devices. As all the used software solutions are containerized, the connection from the field can easily be realized by deployment of gateway containers, i.e. Node-RED, on capable PLCs or SCADA computers. Similarly, the server-side stack is easily reproduced by deployment of component containers on any cloud or own IT infrastructure. Aside from the long list of connectable data sources, Grafana supports integration with different identity and access management solutions such as OAuth and LDAP, allowing for information isolation and customized access for different personnel levels in enterprise environment. Analytics microservices built from Python allows for extensive feature extraction, classifications and clustering on collected building automation data to classify operation modes and identify anomalies where the system is not operating in designed regimes. The analytics results can then be illustrated on Grafana to present the information to process operators and maintenance staffs to perform cause analysis in a timely manner. Finally, the framework is implemented in a modular manner, allowing for adoption of better technologies when available.

The case study is conducted using the framework implementation in Häme University of Applied Sciences infrastructure, as an IoT platform for research and education using the building automation data collected from Sheet Metal Center industrial hall building in Visamäki, Hämeenlinna. Using data collected from the building automation system, the framework is utilized for verification of the heating system functionality and fault diagnostics of the geothermal heat pump using two-step PCA and k-Shape clustering algorithm. The analytics results are then applied to verify the control logic of the building automation system, monitor and improve the heat pump operation and the heating process efficiency. The k-Shape algorithm was able to identify the system's modes of operation: winter or summer, which is then used to perform anomaly detection as the current system sometimes operated in summer mode in winter time. The two-step PCA algorithm was able to detect an undocumented setpoint change in the system, as well as an additional flow of energy in the system; currently used for supervision of process operation in general. Finally, further development of the framework includes extending the analytic features for other buildings and benchmarking of analytics techniques for utilization with automation system data in general.

Keywords: Building automation, IoT, anomaly detection, analytics, two-step PCA, k-Shape clustering

***Corresponding Author: Khoa Dang:** Häme University of Applied Sciences, Finland, E-mail: khoa.dang@hamk.fi

Second Author: Igor Trotskii: Häme University of Applied Sciences, Finland, E-mail: igor.trotskii@hamk.fi

Veli-Pekka Pyrhonen

Robust and perfect tracking control of a DC servo motor

Extended abstract: Robust and perfect tracking (RPT) approach enable engineers to design low-order model-based controllers, which result in closed-loop systems that are able to yield fast tracking of target references with small overshoot. In fact, an RPT controller's performance can be adjusted using a single positive scalar tuning parameter, say ϵ, which guarantees internal stability of the closed-loop system and yields arbitrary fast settling time in the faces of external disturbances and initial conditions as long as control signal is free from physical constraints [1–2]. In reality, physical constraints must be considered, and hence, arbitrary fast tracking can never be achieved.

This paper presents the design of a closed-form parameterized two-degree-of-freedom (2DOF) integrating controller using RPT approach for a DC servo motor application. The DC servo motor application is a Quanser QUBE-Servo 2 unit with a metal disc attachment. The motor unit and disc attachment are depicted in Figure 1.

Figure 1. Quanser QUBE-Servo 2 unit with disc load.

The purpose of the closed-loop control system is to position the disc load from the initial position to final position as fast as possible without overshoot and without violating the actuator saturation constraints. For performance comparison, a 2DOF Proportional-Integral-Derivative (PID) controller with set-point weighting is designed using pole placement method. Both controllers are designed such that they initially use the maximum allowable control effort and yield strictly monotone step response with short settling time.

The simulation and experimental results show that the closed-loop system using the RPT controller yields better positioning performance as measured by the settling time. In addition, the closed-loop system with the RPT controller has larger stability margins and lower sensitivity compared with the system using the PID controller. The closed-loop performance measures are collected in Table 1.

TABLE I. CLOSED-LOOP PERFORMANCE MEASURES.

Indicator	PID	RPT
T_s (ms)	81.1	70.1
T_r (ms)	48.3	42.3
GM	∞	∞
PM (deg)	51.7	60.7
s_m	0.74	0.83
S_{max}	1.36	1.20

In Table 1, T_s is the settling time as measured by the 2% criterion, T_r is the rise time as measured from the time taken by a step response to change from 10% to 90%, GM is the gain margin, PM is the phase margin, s_m is the stability margin, and S_{max} is the maximum sensitivity.

In conclusion, RPT approach offers an attractive design framework for point and shoot tracking problems like the positioning of the disc load in this paper. It is also relatively simple to experimentally tune the RPT controller using the tuning parameter ϵ such that desired tracking performance is obtained and that the actuator saturation constraint is not violated.

[1] Liu K., Chen B.M., Lin Z., On the problem of robust and perfect tracking for linear systems with external disturbances, Int. J. Contr., 2001, 74, 158–174

[2] Cheng G., Peng K., Chen B.M., Lee T.H., A microdrive track following controller design using robust and perfect tracking control with nonlinear compensation, Mechatronics, 2005, 15, 933–948

Keywords: robust and perfect tracking, servo control, control applications, linear systems, saturation

***Veli-Pekka Pyrhonen:** Tampere University, Tampere, Finland, e-mail: veli-pekka.pyrhonen@tuni.fi

Tomi Räsänen*, Veli-Pekka Pyrhönen

State feedback control of a rotary inverted pendulum

Keywords: LQR-control, pole-placement, inverted pendulum, balance control, reference tracking

***Corresponding Author: Tomi Räsänen:** Tampere University (Bachelor's student), E-mail: tomi.rasanen@tuni.fi
Veli-Pekka Pyrhönen: Tampere University, E-mail: veli-pekka.pyrhonen@tuni.fi

Extended abstract. Regulating a pendulum link to the upright position is an application of a mechanical balancing problem. An-other well-known example of such a balancing problem is Segway, where a controller has to prevent the machine from falling when a user shifts her center of gravity. The controller should also maintain a correct velocity of Seg-way depending on its angle from the upright position. This paper investigates linear state feedback control of a rotary inverted pendulum, which is attached to Quanser QUBE - Servo 2 base unit as in Figure 1.

Figure 1. Quanser QUBE - Servo 2 system

The system consists of a pendulum link and a rotary arm. The pendulum can spin freely around the rotary arm, which can be turned ±90° about its pivot point. The rotary arm is mounted to the base unit with magnets. The system has three measurements; namely, input voltage and angles of the rotary arm and the pendulum link. Quanser has implemented so-called "Swing-up" - control to the inverted pendulum system, which is used to raise the pendulum link to the upright position. Feedback controllers in this paper are designed to 1) regulate the pendulum link to upright position and 2) enable the rotary arm to turn from one angle to another while satisfying two restrictions. The first restriction concerns the DC motor input voltage, which is limited by $\pm 15V$. Additionally, the pendulum link must not deviate more than 20° from its upper position, or the system could become unstable. For the above reasons, the problem considered in this paper is an example of simultaneous regulation task and a reference tracking scenario.

In this paper, two LTI-state feedback design tools are utilized; namely, the pole-placement method and the Linear-Quadratic-Regulator (LQR) control. With both of these tools, a stabilizing state feedback gain is obtained. The design methods produce separate controllers whose performances are evaluated based on settling time (t_s), rise time (t_r) and maximum overshoot (M_p) of responses. The best controller is simulated using Simulink software and tested with the actual device. The realized transient response characteristics of the system are t_s = 3.90, t_r = 0.966 and M_p = 2.48.

Mats Friman*

Fault-Tolerant Valve Control

Abstract: Valves have a key position in safe, reliable, and economical operation of process industry plants. Valves consist of moving parts subject to wear and dirt. During a fault, it is important that the valve controller eagerly tries to keep the valve under control, despite of changes in the operating environment. In this paper we discuss valve faults on a general level, and we present a solution for keeping valve under control despite of a missing valve position measurement. Our solution utilizes valve/actuator models and real-time simulations to generate a virtual valve position sensor. When valve position measurement is lost, the controller will continue as before, but the real position measurement is replaced with a soft sensor value.

Keywords: industry, valve, valve controller, fault-tolerant control

*Corresponding Author: Mats Friman: Metso Flow Control, E-mail: firstname.lastname@metso.com

1 Introduction

Process industry plants, such as oil refineries, pulp mills and chemical production plants, are highly automatized. The automatic operation is based on a network of sensors, controllers, and actuators.

The most common actuators are the valves, which are used to control liquid and gas flows in pipelines. An industrial valve consists of three parts: 1) a valve body, attached to the pipeline, 2) a pneumatically powered actuator, and 3) a valve controller, which controls the valve position according to the setpoint obtained from the process automation system [1]. Today's valve controllers are intelligent digital devices with various features that supports plant operation during its entire life time.

The valves have a key position with respect to safe and reliable operation of the plant. It is important that all devices contribute to safe and controlled responses during a failure. A wide range of options must be supported: from continued operations (with some reduced performance) to a safe and controlled shut down.

Some valves may have a critical position regarding plant operation, i.e. if a valve fails, the entire subprocess must be shut down. Therefore, a valve controller should eagerly fight against faults and try to keep valve under control despite of minor faults. A difficult case is loss of valve position measurement. In this paper we discuss some safety and fault-tolerant features of the Neles NDX valve controller, and we present a method for keeping control over the valve in case of a faulty valve position sensor.

2 Valve controller basics

A valve controller has two main tasks. First it receives a valve position setpoint, typically from a process automation system, and secondly, it controls the valve position according to the setpoint.

A typical valve controller is illustrated in Figure 1. The main components include a PCB with integrated sensors, a Prestage unit (an I/P converter), and an Output Stage (a pneumatic relay).

A local user interface enables easy commissioning and a possibility for manual operation and parameter changes. The milliampere signal powers the device and provides analog setpoint and standardized HART digital communication. A set of sensors provide necessary measurements needed for valve control, and a position transmitter enables an analog valve opening signal.

The microprocessor compares valve position measurement to its setpoint and generates an electrical signal to the Prestage. The Prestage pressure actuates the Output stage, which controls air flow into or out of the actuator. The valve controller keeps adjusting the Prestage signal until the valve reaches its desired position [2].

Valve controllers have traditionally employed some feedback control algorithm for controlling the valve position. If actuator pressure measurements are available, some cascade control structure can be used to speed up valve control. An example cascade control structure is illustrated in Figure 2.

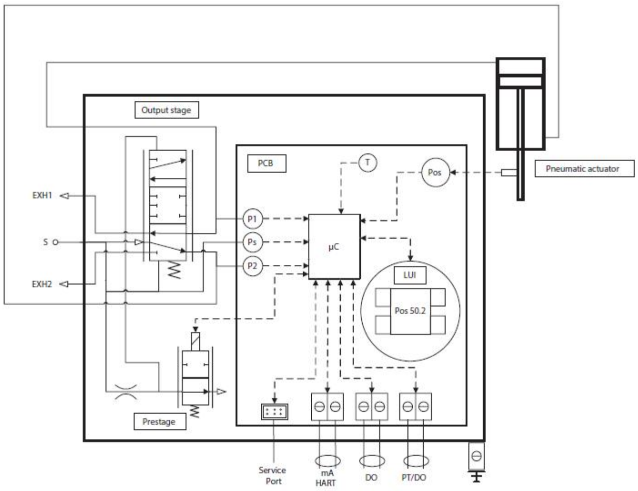


Figure 1. Operating principle of a valve controller.

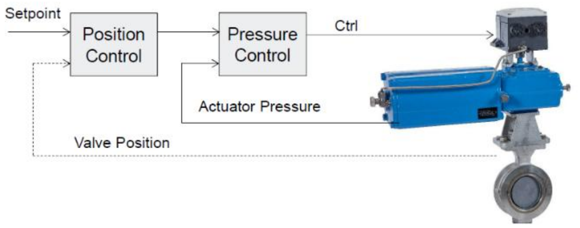


Figure 2. A typical valve control structure based on valve position and actuator pressure measurements.

3 Valve Faults

Various faults may occur during valve operation. We can divide faults into two categories: faults that imply loss of controllability and faults with retained controllability. If we lose valve controllability, e.g. during loss of pneumatic pressure or electrical power, then valve moves to a pre-determined fail-safe position.

If controllability of valve is retained, we can further divide the faults into two categories: 1) mechanical faults and 2) sensor faults. Typically, mechanical faults affect control performance but does not necessarily imply a need for urgent replacement of faulty valve package part. However, depending on the fault and its severity, we typically get some increased position control error or valve hunting as a result.

The most critical sensor for valve control is the valve position sensor. For any other sensor fault, we can switch to simple position feedback control during a fault.

The Neles NDX valve controller position measurement is based on a magnet sensor. This solution has many advantages as it enables accurate position sensing without mechanical links in harsh conditions. However, if the magnet is significantly moved away from its original position or if the positioner or its bracket is moved, tilted, or rotated, it may affect sensor reliability. Therefore, situations may occur where NDX cannot access the position measurement. To prevent an unplanned shutdown because of missing valve position readings, we have developed a method for valve position control without position measurement.

4 Fault-tolerant control

With fault tolerant control we mean the ability of a controller to retain controllability despite of faults in the control network. Usually we tolerate some reduction in the control performance, but the main goal is to continue running the process despite of the fault.

For valves, fault-tolerant control due to mechanical faults and sensor faults are discussed next.

Mechanical faults

Typical problems in valve control include air leakage in pneumatic actuator, increased friction in valve body, freezing, and valve controller faults (e.g. defectives in pneumatic components). These faults may affect valve control accuracy, but normally we can continue operation without a need for replacement of devices or spare parts.

For mechanical faults, fault-tolerant control typically means detuning of controller to avoid valve hunting. Large control errors may also need special attention.

Mechanical faults are recognized by valve controller diagnostics, and the faults are communicated to the maintenance organization [3].

Auxiliary sensor faults

In addition to valve position, which is the controlled value, valve controllers typically have auxiliary sensors, which speeds up and improves position control. Auxiliary sensors are e.g. supply and actuator pressures, and temperature. In case of a failure in any of the auxiliary sensors, the controller switches to a position-feedback mode where control actions are based on valve position only.

Faults in position sensor

On a general level, a feedback control loop needs both a setpoint and a measurement. A fault in the controlled value (i.e. measurement fault) prevents us from utilizing feedback control. Instead, feedforward control must be used to ensure that the (unmeasured) controlled value responds to changes in the setpoint.

For a valve controller, if there is a fault in the position sensor, the only option is *feedforward* control of valve position.

An intuitive solution for the cascade control setup in Figure 2, where the dotted line indicates a faulty or missing position measurement, would be replace the "Position Control" block, with e.g. a look-up table that picks a setpoint for actuator pressure based on given position setpoint. In this case, the look-up table would act as a feedforward controller, and replaces the feedback controller, which cannot operate because of the missing measurement needed for feedback control.

Next, we will present an alternative solution. We will replace the missing position measurement with a soft-sensor and continue with the same feedback controller as before [4]. The advantage of this solution is that there is no need for a separate feedforward controller. Instead, the same feedback controller can be employed both for ordinary feedback control and for control during a fault in position measurement. All we need is a model and a valve position simulation engine, which generates a virtual valve position value during a valve position failure. A simple model, which is easy to simulate is utilized [5,6,7].

Valve and actuator model

Consider a single acting, spring/piston actuator connected to a valve (Figure 3). The actuator consists of a spring pushing in one direction, and air pushing in the opposite direction. When air flows into/out of actuator, actuator pressure changes, and valve moves.

Compressed air in the actuator initiates a force that is proportional to air pressure. According to Hook's Law, the spring force is proportional to spring contraction [8] and considering pneumatic and spring forces (before considering friction) we notice that actuator travel (and valve opening) is proportional to actuator pressure. Introducing Coulomb friction, the net spring and pneumatic force must exceed the Coulomb friction threshold to ensure that the valve is moving.

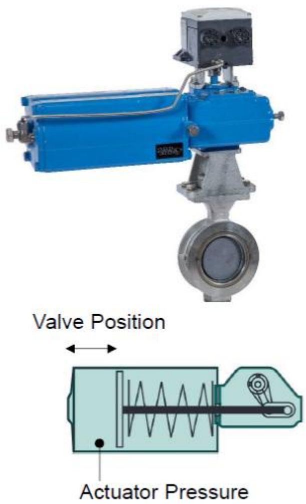


Figure 3. A valve package (above) and a detailed view of the single acting spring-return actuator (below).

A typical response of actuator movement to pressure changes is shown below (Figure 4) where we have plotted valve position vs. actuator pressure for an example actuator. Different colors indicate different movement directions. From this figure it is clearly seen that valve position is linear with respect to actuator pressure for each movement directions. However, because of friction forces, there is a clear gap between movement up and down curves (i.e. the Coulomb friction).

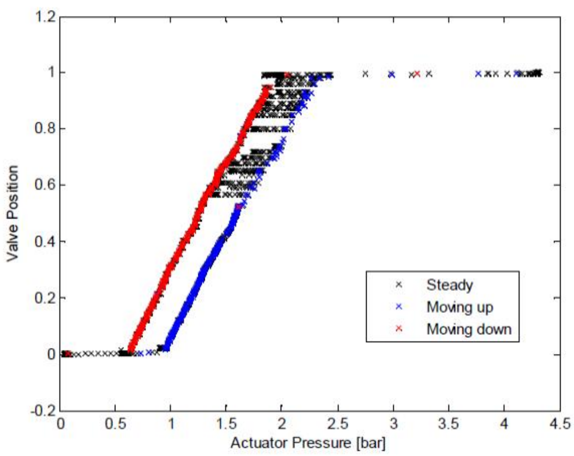


Figure 4. Valve position vs. actuator pressure for an example spring-return actuator.

Soft sensor

Above we observed a linear relationship between valve position and actuator pressure, when moving in one direction (up/down cases indicated by red/blue colors). Based on this finding we used the following equality for estimating new valve position h_e actuator pressure p_a

$$h_e = \begin{cases} \min\left(1, max\left(0, \frac{p-p0-pf}{k_s}\right)\right) & if p > h_o k_s + p_0 + p_f \\ \min\left(1, max\left(0, \frac{p-p0+pf}{k_s}\right)\right) & if p < h_o k_s + p_0 - p_f \\ h_o & \text{otherwise} \end{cases}$$

(1)

where the parameters p_0 is the actuator pressure which equals spring pretension, p_f is net coulomb friction in pressure units, and k_s is spring constant (in pressure units / full stroke). The simulated position h_o is the only state variable needed for the simulation.

Device calibration includes an automatic tuning sequence, which moves the valve in both directions. This sequence enables reliable identification of the three parameters p_0, p_f, and k_s of Eq. 1. Note that for valve opening values between the extreme values (fully open/close), Eq. 1 is linear in the parameters.

The valve controller can switch to missing-valve-position-measurement mode automatically if it recognizes problems in position measurement. Alternatively, we can manually switch to fault-tolerant mode.

5 Results

We tested the suggested fault-control strategy by running a control valve in the laboratory. During the test we used a manual mode selector to switch between normal control and fault-tolerant mode with real position measurement replaced by soft-sensor value.

To demonstrate the robustness of the suggested method, we selected a high-friction valve for testing. For the test valve, the pressure change needed for valve reversal is 0.6 bar (i.e. pressure to compensate for friction), which can be compared to pressure change of 1.0 bar needed to compensate for spring forces during entire moving range (close to open). With such a large friction values, it is difficult to position the valve, especially when running in fault-tolerant mode.

An example test run is shown below in Figure 5 where trends for ordinary control which uses valve position, and fault-tolerant mode are shown. We used a setpoint sequence consisting of a ramp, and some step changes. The colors indicate the two different experiments: blue lines for ordinary control (which utilizes position measurement) and green lines for fault-tolerant control mode (when position measurement was neglected by the controller but recorded for trend plotting purposes).

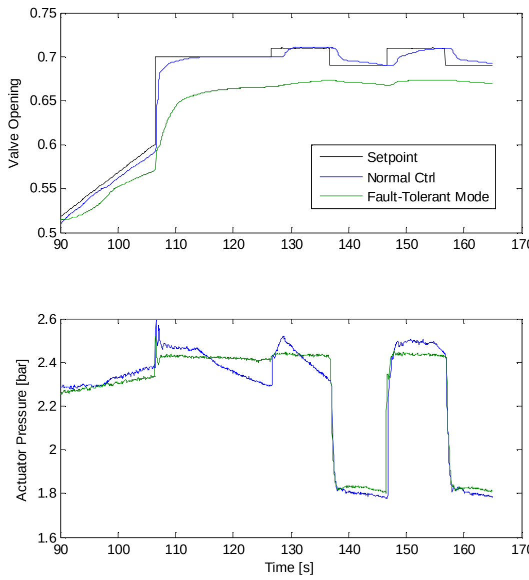


Figure 5. Comparison of control performance with normal control (blue) and with fault-tolerant control (green), which does not utilize position measurement. Above valve opening and setpoint, below actuator pressure.

6 Summary

We have developed a method for keeping a valve under control despite of loss of valve position measurement. Our solution is to replace the missing position measurement with a virtual measurement obtained from real-time simulations of valve. The same controller is used in both modes: closed-loop control (with position measurement from real sensor), and fault-tolerant control mode (with virtual measurement used for control).

Our test results from running a high-friction valve in laboratory suggest that valve control based on a virtual measurement works very well. The results demonstrate that the control accuracy suffers a little bit, as the control error increases with a few percentage points when operating the valve in position sensor-fault mode.

Because of the missing position sensor, it is impossible for the valve to follow its setpoint exactly. This is not a serious problem for valves operated by a PID control loop, because valve position errors are compensated by the PID controller. Control loops operated in manual mode, on the other hand, are expected to have a steady-state deviation in valve position.

The advantages with the suggested feature is that we can avoid an unplanned shut-downs of plant. This is expected to provide cost savings, added flexibility and more options for maintenance planning.

References

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

[2] Metso Flow Control: NELES® INTELLIGENT VALVE CONTROLLER, SERIES NDX. Technical Bulletin. 2016.

[3] Manninen T. Fault Simulator and Detection for a Process Control Valve. PhD Thesis, Aalto University, Espoo, Finland 2012.

[4] Friman M., Heikkinen P. Method and Controller for Actuator, Patent Application, WO2018/055229Al, 2018

[5] Hietanen V., Friman M., Pyötsiä J., Manninen T. Laatua järjestelmien simuloinnista. Automaatio XIX seminar. Finnish Society of Automation. Helsinki, Finland. 2011.

[6] Friman M. Model-Based Design: Experiences from Valve Controller Development. Automaatio XXII seminar. Finnish Society of Automation. Vaasa, Finland. 2017.

[7] Pyötsiä J. A Mathematical model of a Control Valve. PhD Thesis. Helsinki University of Technology, Espoo, Finland. 1991.

[8] Wikipedia. https://en.wikipedia.org/wiki/Hooke%27s_law Accessed 10.3.2019

Hans Aalto*

Estimating the dynamic characteristics of natural gas transmission systems

Keywords: Gas pipeline dynamics, time constant, dominating time constant

***Corresponding Author:** Hans Aalto, Neste Engineering Solutions Oy, POB 310, 06101 Porvoo, Finland, E-mail: hans.aalto@neste.com

Extended abstract. The first-principles mathematical models describing natural gas transmission systems are non-linear partial differential equation (PDE) systems with respect to space and time. Those PDE's apply for each individual segment of pipeline, and in addition models describing other components of the transmission systems such as compressors, valves, heat exchangers, storages, etc. are described by ordinary differential equations (ODE) or algebraic equations. All those models can be integrated to one dynamic transmission system model which can be used to investigate the behavior of the system in different operational situations (simulation), or to figure out how the system can be operated in the best way (off-line optimization) or to find the maximum gas transmission capacity in different situations (capacity planning). Commercial transmission system models (TSM's) have been available on the market for many years, and they are known to be very accurate given that the various parameters, such as pipeline geometry, gas composition, friction, compressor characteristics, etc. are correctly entered into the models.

Commercial TSM's are convenient tools when use only for the purpose they have been designed for, but extended use scenarios may provide difficulties. For instance in USA, the natural gas and electrical power markets are getting increasingly integrated [1], [2] and the integration of TSM's and power grid system models tend to be difficult because the execution time of the more complex TSM's becomes prohibitive. Therefore, there is a demand for simplified TSM's. Other motivations for simplified models come from control design and model-predictive control (MPC) for gas transmission systems. In [3] it was demonstrated by a case example that the dynamics of gas transmission systems are, after all, not very non-linear. Simple formulas for the transfer function gains of gas transmission systems were derived in [3] and [4]. There is unfortunately no simple way to conclude the time constants of the linear transfer functions. [4] suggests constrained system identification and [5] a procedure based space discretization and linearization of the PDE's followed by a model reduction step which provides a low-order linear state-space model from which the time constants can be easily extracted.

In [6] a different approach is used: The PDE's are linearized based on certain assumptions and non-rational transfer functions are obtained. Those non-rational transfer functions are then used to provide simulations in the time domain. In [7], the non-rational transfer functions are approximated by Taylor expansions from which the time constants can be easily calculated. The assumptions used do not always hold, and the authors do not present how to treat more complex transmission systems than the single pipeline segments they treat, namely, branched pipelines, pipelines with loops, and transmission systems with multiple pieces of equipment like compressors and valves.

The paper presents a new and practical method to calculate the linear transfer function time constants for gas transmission systems. If a first-principles TSM is available, that is simply used to by multiple simulation experiments - step tests - calculate the time constants so that transmission system parameters (gas throughput, pipeline geometry, friction, compressor data, etc.) are varied according to a pre-defined pattern. The result of these tests is a table of system parameter values and resulting time constants, and simple functions relating parameter values and values of time constants can be derived by regression.

The paper also discusses the very concept of "time constants": it is well known that even the smallest gas transmission system, eg. one short pipeline segment, has a linearized transfer function with multiple descending de-nominator time constants. It is easy to find the dominating time constant, but how many of the non-dominating are needed to describe the dynamics with reasonable accuracy. In [3] it already became clear that the numerator time constant(s) has relevance depending on the location of the output variable within the transmission system.

References

[1] Carter, R., S. Backhaus, A. Hollis, A. Zlotnik, M. Chertkov, A. Giacomoni and A. Daniels, Impact of Regulatory Change to Coordinate Ga Pipelines and Power Systems, Pipeline Simulation Interest Group (PSIG) annual meeting, May 2016, Vancouver, Canada

[2] Zlotnik, A., M. Chertkov, R. Carter, A. Hollis, A. Daniels and S. Backhaus, Using Power Grid Schedules in Dynamic Optimization of Gas Pipelines, Pipeline Simulation Interest Group (PSIG) annual meeting, May 2016, Vancouver, Canada

[3] Aalto, H. , Optimal Control of Gas Pipeline Networks, a real-time, model-based, receding horizon optimisation approach, 186 pages, VDM Verlag Dr. Müller Aktien-gesellschaft & Co. KG, Saarbrücken, Germany, ISBN 978-3-639-09111-3, 2008

[4] Aalto, H., Model Predictive Control of Natural Gas Pipeline Systems - a case for Constrained System Identification 9th IFAC symposium on Control of Power and Energy Systems, 9-11 December 2015, New Delhi, India, www.ifac-papersonline.net

[5] Aalto, H., Transfer functions for Natural Gas Pipeline Systems, 17th IFAC World Congress, July 6-11 2008, Seoul, South Korea, www.ifac-papersonline.net

[6] P. Lopes dos Santos, T-P Azevedo Perdicou'lis, J. A. Ramos, G. Jank, J. L. Martins de Carvalho and J. Milhinhos, A Lumped Transfer Function Model for High Pressure Gas Pipelines, 49th IEEE Conference on Decision and Control (CDC), 15-17 Dec. 2010, Atlanta, USA

[7] Wen, K., Z. Xia, W. Yu and J. Gong, A New Lumped Parameter Model for Natural Gas Pipelines in State Space, Energies 2018, 11, 1971, www.mdpi.com/journal/energies

Extended Abstracts
ISBN 978-952-5183-56-6

Yrjö Majanne*, Tomas Björkqvist, Pertti Järventausta, Matti Vilkko

Modeling and optimization of distributed energy resources microgrids

Keywords: microgrid, optimization, modelling

*Corresponding Author: Tampere University, yrjo.majanne@tuni.fi

Other Authors:
Tampere University, tomas.bjorkqvist@tuni.fi;
Tampere University, pertti.jarventausta@tuni.fi;
Tampere University, matti.vilkko@tuni.fi;

Extended abstract. Microgrids are electricity distribution systems containing loads and distributed energy resources, such as distributed generators, storage devices, and controllable loads. Microgrids can be operated either while the system is connected to the main power grid or while the system is islanded (off-grid).

The paper will present early results from modelling and optimization of the operation of a case system, which is under construction at Lempäälä, in Marjamäki industrial and commercial area. Marjamäki grid will consists of 4 MW solar power plant, total of 8.4 MW gas engines for CHP production, two 65 kW fuel cells, 2.4 MW/1.6 MWh (charge and discharge power/capacity) electrical energy storage system, heat and cooling storages, smart buildings having their own generation resources and demand response functionalities, and intelligent grid automation and management systems. The microgrid has a medium voltage connection to the grid of the local distribution system operator (DSO), and its own gas and district heating networks.

The intelligent microgrid environment aims to cost efficient utilization of all resources available at the energy community consisting of the members connected to the microgrid. Key features are energy conservation and promotion of circular economy through energy networks. An important topic is the creation of incentives for investments in community-friendly energy solutions. The energy community perspective should be promoted by optimizing the network performance so that community costs are minimized when members' costs are minimized instead of individual player focused local optimization.

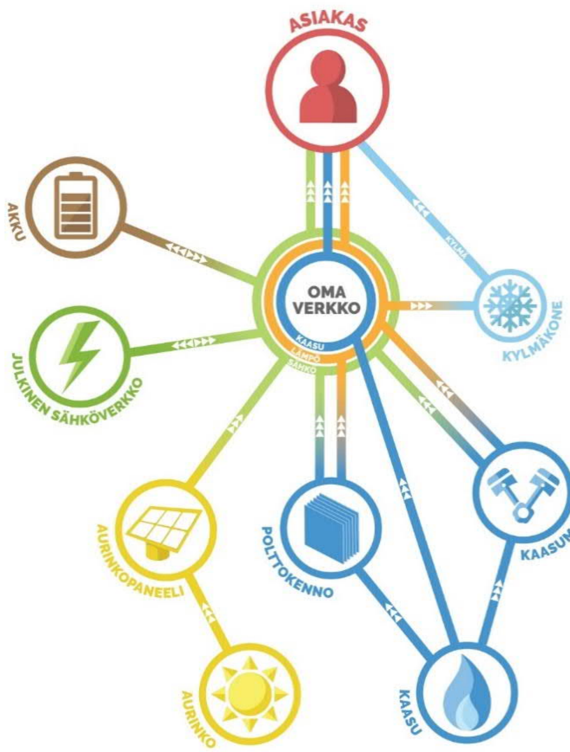


Figure 1. Structure of the Marjamäki microgrid.

Microgrid Model.

The operation of the microgrid system is studied with a dynamic simulation model. The model consists of power flows between consumer and producer nodes and the grid connection with the DSO network. Consumption and production data is provided with hourly-based time series data. System formulation is carried out by General Algebraic Modelling Systems GAMS as well as optimization of operation costs as a function of electricity price in spot market and own generation potentials. The model variables are

- power flow from/to DSO grid
- power flow between microgrid and battery energy storage (BES)
- charge level of BES
- cost of grid electricity
- cost of generation by fuel cells
- cost of generation by gas engines

The case study is calculated based on hourly data from year 2017 including

- Nordpool Elspot Day ahead price [€/MWh]
- electric power consumption at microgrid area [MWh/h]
- heating power consumption [MWh/h]
- solar intensity rate
    - measured from the roof of the Electrical Engineering building at Hervanta Campus, Tampere

System operation related boundary conditions are

- Allowed battery charge level 30 – 90%
- upper limits for generation and battery charging/discharging capacities
- battery charge level at the beginning and the end of the optimized day
    - 24 h net use equal to zero

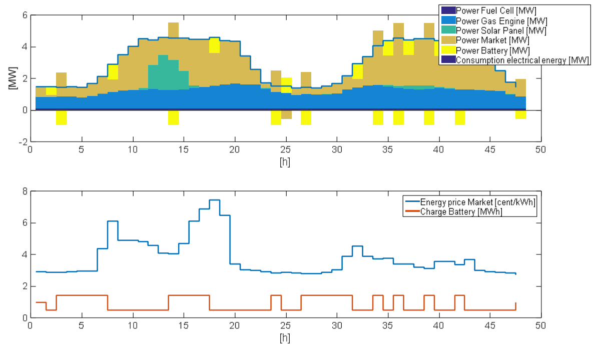
Model equations

- momentary power balance between consumption and production
- battery dynamics (calculation of battery charge level)
- cost function, minimize the sum of operation and purchasing costs

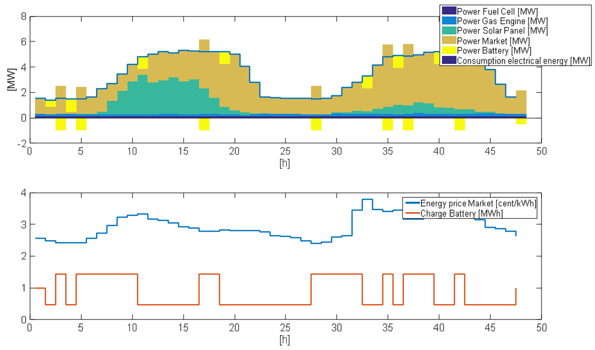
<u>Optimization results</u>

Figures 2 and 3 show the optimization results from two 48 hours periods on the January 24.-25. and on the July 18.-19. 2017. The optimization problem is to minimize the supply costs of electric energy by the active use of the battery storage. During both periods, the fuel cells were operated at full capacity and gas engines were operated according to the heat load (CHP generation). Solar PV generation capacity is calculated according to the measured solar irradiation data. Yellow bar on positive power side indicates discharging and negative bar charging of the battery storage (direction of power flow from battery to microgrid). During the January period, the gas engines are intensively used for heat production and solar PV generation capacity is minor, especially on 25.1. During the period on July, solar PV generation is more intensive, but the heat load and thus the gas engine generation is negligible.

Figures 4 and 5 show histograms and duration curves of load and generation levels calculated from year 2017 data. On the first row of Figure 4, two first histograms show electricity and heat load distributions. The third histogram is the generation capacity of fuel cells, which is constant 65 kW all through.

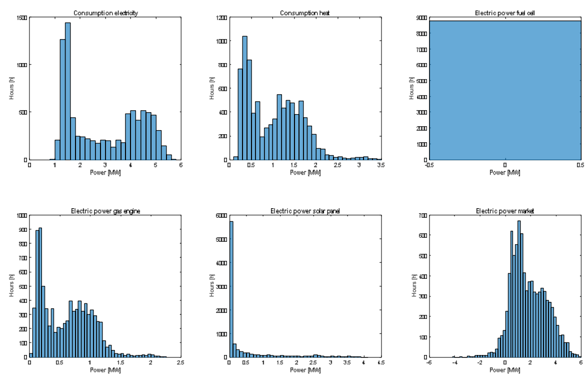


<u>Figure 2.</u> Optimization of supply cost of electric energy on 24.-25.1.2017.



<u>Figure 3.</u> Optimization of supply cost of electric energy on 18.-19.7.2017.

On the second row there are power level distributions of gas engines and solar PV generation and buy/sell electricity from the grid. It can be seen from the histograms that e.g. solar PV generation is very modest. From 4 MW installed capacity during app. 5800 hours from annual 8760 hours, the generated power has been between 0-100 kW. However, this is not a typical situation because summer 2017 was exceptionally rainy and cloudy. However, this kind of situations should also to be taken into account, when planning weather dependent generation systems.



<u>Figure 4.</u> Histograms of hourly power levels of consumptions and production capacities.

The third histogram on row two shows that most of the time the microgrid is buying electricity from the grid.

Duration curves presented in Figure 5 show the same information as histograms in figure 4.

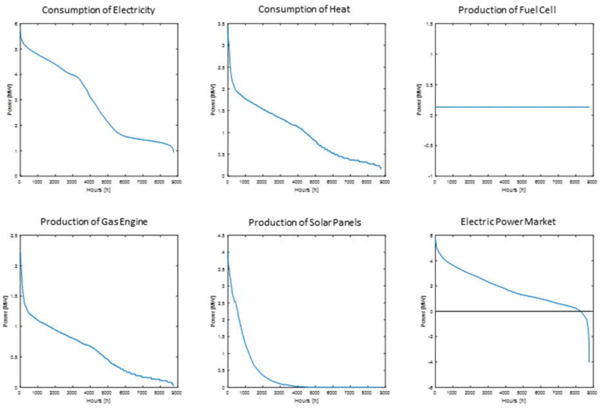


Figure 5. Annual duration curves for loads and production resources.

The two first curves on the first row show durations of electricity and heat loads. The third curve is the constant 65 kW generation from fuel cells. On the second row the two first curves show the duration levels of gas engine electric power and solar PV generation. The third curve shows that most of the time the microgrid is buying electricity from the grid.

Conclusions and Next Steps

Marjamäki microgid offers a remarkably versatile environment for microgrid related research activities in general, such as:

- MW-level large-scale solar power system and several smaller PV units located in the buildings
- Management and automation solutions of the microgrid system operating in parallel with the supplying network of the local DSO or as a separated island
- Utilizing the microgrid and its various resources as a flexible resource for frequency controlled reserve markets in the national power system
- Using microgrids to improve security of supply of the DSO as an alternative to other options (e.g., cabling in rural areas)
- optimization of various energy resources in resource efficient energy management
- regulation, roles and business of different actors in the microgrid framework

The next steps in the development of Marjamäki area are adding the generation and flexibility resources of the energy community and minimizing of the total costs. An important goal is the development of an internal cost-sharing mechanism so that the cost of the community is minimized when the cost of the members is minimized. This will lead to the process aiming at the optimal development of the whole area instead of short time benefits of individual players.

Petteri Lehtonen

Successful I&C Renewal Project of Loviisa NPP

Keywords: Energy production, Nuclear power, digital safety automation, project life cycle, systems engineering, licensing, simulators

***Corresponding Author: Petteri Lehtonen:** Fortum Power and Heat Oy, Finland, E-mail: petteri.lehtonen@fortum.com

1. Introduction

Loviisa VVER-440 plant units were originally commissioned on 1977 and 1980. The status of instrumentation and control (I&C) systems was clarified after 30 years of operation, as manufacturing of original components and spare parts had been stopped. In early 2000s it was decided to set up an I&C renewal project to ensure licensability and high availability of the plant and to improve the maintainability by securing sufficient supply of spare parts and knowledgeable personnel until the end of plant lifetime. The renewal scope would address the most important safety and licensing questions: renewal of critical safety and safety related I&C systems with modern safety requirements, addition of new safety related and non-safety preventive functions together with relevant manual and automatic back-up systems, provision or clear separation and prioritization between the systems in different defence-in-depth levels. Digital I&C platforms were chosen for all safety, safety related and non-safety systems. Comprehensive hardwired and digital backups with diverse technology were planned for the most essential safety systems.

A full scope I&C renewal project LARA was initiated with Areva and Siemens Consortium in 2004. Since the beginning it was noticed that modernizing full scope of nuclear power plant I&C together with plenty of safety improvements brings lot of complexity and requires chunking the renewal into several stages in order to keep the scope and commissioning duration manageable. This again presented a need for numerous intermediate solutions. The first renewal stage was successfully commissioned in outages 2008, 2009 consisting of Preventive Protection System (reactor's fast and slow shutdown, control rod control and position indication), incore measurement system and normal process control systems.

The challenges faced consisted of e.g. modern requirement based design, large architecture, qualification of digital I&C and vast intermediate solutions between renewal stages. After several postponements of commissioning date for the most important 2nd renewal stage, many accruing and waiting change needs of operating plant were forced to be included in the project scope. This induced growing risks related to the estimated duration of commissioning outage and the commencing year, and no clear visibility meeting the project's original targets.

2. Second I&C renewal project ELSA

Based on the difficulties a new plan was prepared. The new ELSA I&C renewal project included substantially smaller scope, and would renew only most critical I&C systems with most essential safety improvements. Delivery limits were carefully prepared and responsibilities shared between the utility and the new supplier Rolls-Royce Civil Nuclear in an optimal manner. The project duration was kept as short as possible to minimize emerging plant change needs and thus to keep the configuration manageable. The project scope was planned to be commissioned in three consecutive outages, both plant units at the same year, with keeping regular outages durations with tolerable risk for additional delays.

Pre-approval for the planned scope and equipment was sought in the conceptual design phase from the regulator. New ELSA-R program together with program management routines were established to govern the closely related projects of the ELSA project and thus to secure successful execution of the projects. The new smaller scope also meant identification of maintenance and renewal needs for the existing and remaining I&C parts and management of them as separate spare parts or renewal projects under normal plant governance.

3. APROS® testing

Simulators were planned to be used in many areas of the ELSA project since the beginning. This was due to versatile APROS® tool and good experiences from other projects. At first all safety analyses were renewed with the new plant functional architecture. After validating the plant functionality the new I&C systems were validated against the simulated plant model. The simulation environment made validation against the simulated plant possible to be done at an early phase of the project, and to include plant operators already at this early phase. Also errors were discovered early on and the tuning of the reactor power controller was possible before commissioning. No real modifications to the systems were needed to be done at the plant.

For testing the I&C architecture in an efficient and flexible manner a completely new plan was prepared. For most extensive last renewal stage a test platform of 7 individual I&C systems was set up at the supplier's test field. In addition the supplier's separate test connection equipment the APROS simulator was interconnected with the I&C. This provided two advantages: the possibility to run test cases against the simulated plant, and emulating I&C systems in simulator environment before the software & hardware detail design of all systems was ready. First all seven I&C systems were tested with emulations. One by one after completion the real I&C systems replaced the corresponding system emulation in the test configuration, leading in the end to all the seven real I&C systems being interconnected and APROS used as a simulated plant model.

This enabled saving months from testing time of interconnected tests. The interconnection functionality between systems was possible to be tested well in advance, and only in the end when all seven systems were ready and interconnected hardwired, comprehensive testing of actual interconnections themselves was done to confirm that no differences between simulated and real environments existed.

The test platform was also used for additional functional testing based on regulator request. The test simulator made it possible run complex accident scenarios outside the planned test procedures, testing the I&C architecture and systems both in design basis and beyond design basis cases. These test cases were consisting for example of complete blackout of half of the I&C system cabinets and large common-cause failure (CCF) of actual safety class 2 safety systems together with an accident scenario. The simulation of these cases confirmed that that the diverse automatic backup system using different measurements and functions from actual safety system was able to trip the reactor. Also all the two and four redundant system architectures with separated power supplies worked as planned. These tests proved the solidity of the architecture and that the diversity was correctly applied in defence-in-depth concept.

4. Conclusions

Loviisa I&C renewal project was set up to ensure licensability and high availability of the plant and to improve the maintainability by securing sufficient supply of spare parts and knowledgeable personnel until the end of plant lifetime. The first full scope renewal project proved to be extremely challenging due to scope, safety improvements and emerging change needs. New ELSA project included substantially smaller scope, and would renew only most critical I&C systems with most essential safety improvements. The corner stones of successful implementation of ELSA on time and within budget proved to be on technical side the clear ADLAS® plant and safety documentation, utilization of APROS® simulators, meticulous definition of scope, architecture and the interfaces. From project point of view the optimized share of responsibilities, active schedule management and risk mitigation based on it, planning of licensing documentation schedule and most importantly of all a shared mindset and a common goal between Fortum and the Supplier secured the project to meet the expectations.

Jussi Sihvo*, Joona Leinonen, Tomi Roinila, Tuomas Messo

Jatkuva-aikaiset impedanssimittaukset osana älykkäitä akkujärjestelmiä

Avainsanat: Litium-ioni akku, Akun impedanssi, jatkuva-aikaiset mittaukset, älykkäät akkujärjestelmät, kuntotila, varaustila

***Vastaava kirjoittaja: Jussi Sihvo:** Tampere University of Technology, E-mail: jussi.sihvo@tuni.fi

Joona Leinonen: Tampere University of Technology, E-mail: joona.leinonen@tuni.fi

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

Tuomas Messo: Tampere University of Technology, E-mail: tuomas.messo@tuni.fi

Laajennettu Tiivistelmä

Li-ion akkuja hyödyntävien sovellusten, kuten esimerkiksi sähköisen liikenteen ja uusiutuvan energian, määrä on merkittävästi kasvanut viimeisten vuosien aikana. On arvioitu, että akkujen globaalit markkinat ylittävät 100 miljardia euroa vuoteen 2030 mennessä [1]. Tämä on asettanut haasteen kiertotaloudelle, sillä noin 95% akuista päätyy jätteeksi kierrättämisen sijaan. Tutkimukset ovat kuitenkin osoittaneet, että jopa 95% li-ion akuista olisi mahdollisuus uusiokäyttää osittain tai kokonaan [2].

Li-ion akut tarvitsevat toimiakseen akun valvonta-järjestelmän (battery-management-system (BMS)), joka mahdollistaa akun turvallisen, sekä optimaalisen käytön. Akun tilaa indikoidaan akun valvonta-järjestelmässä akun tilaparametrien, kuten varaustilan (state-of-charge (SOC)) ja kuntotilan (state-of-health (SOH)) avulla. Varaustila kertoo, kuinka paljon akussa on varausta jäljellä ja kuinka paljon akku pystyy toimittamaan energiaa [3]. Akun kuntotila taas indikoi akun jäljellä olevaa käyttökapasiteettia, sekä akun kykyä toimia sen nykyisessä sovelluksessa [4]. Parametrien tarkka määrittäminen on kuitenkin haasteellista, sillä SOC ja SOH riippuvat myös akussa vallitsevista olosuhteista, kuten lämpötilasta ja akun sisällä tapahtuvista kemiallisista reaktioista [5]. Lisäksi kyseiset parametrit täytyy määrittää epäsuorasti akun jännite-, virta- ja lämpötilamittauksin [6]. Erityisesti akun kuntotilan monitorointi on haasteellista, sillä akun kunto riippuu myös nykyisen kapasiteetin lisäksi hyvin paljon siitä, kuinka ja missä olosuhteissa akkua on aiemmin käytetty ja kuinka kapasiteetti on laskenut. Luotettavaan kuntotilan monitorointiin tarvitaankin läpi akun eliniän kestävää monitorointia, jotta vikaantuneet kennot voidaan havaita ennen kuin niiden kunto on laskenut liikaa [7].

Akun kapasiteetti voidaan mitata purkamalla akku täydestä tyhjäksi ja laskea akusta purettu varauksen määrä. Kyseinen menetelmä kuitenkin vie hyvin paljon aikaa ja kuluttaa akkua turhaan eikä näin ollen sovellu akun kuntotilan mittauksiin. Tutkimukset ovat kuitenkin osoittaneet, että Li-ion akun sisäinen impedanssi vaihtelee paitsi akun kapasiteetin ja kuntotilan, myös varaustilan funktiona [3-8]. Akun impedanssin mittaus tarjoaa siis vaihtoehtoisen tavan määrittää akun kunto- ja varaustila. Akun impedanssi voidaan mitata elektrokemiallisen impedanssi-spektroskopian (EIS) avulla. EIS-menetelmässä akkua puretaan/ladataan sinimuotoisella virta- herätteellä, jonka tuottama jännitevaste mitataan jännitesenso-reilla. Menetelmällä voidaan impedanssi mitata tarkasti ja luotettavasti, mutta tekniikka on huonosti sovellettavissa käytännön sovelluksiin sen hitauden ja kompleksisuuden takia.

Tässä työssä hyödynnetään laajakaistaista, pseudo-satunnaista binääristä herätesignaalia (PRBS) sekä Fourier-tekniikoita akun impedanssin mittauksiin [11]. Menetelmässä akkua herätetään (ladataan/puretaan) pieniamplitudisella, kaksitasoisella herätesyklillä, jonka avulla akun impedanssi voidaan mitata useilla eri taajuuksilla samanaikaisesti. Näin mittaukset voidaan suorittaa vain murto-osalla ajasta joka kuluisi perinteisiin EIS-menetelmän mittauksiin. Nopeutensa ansiosta PRBS-menetelmää voi käyttää jatkuva-aikaisiin sovelluksiin, joita ovat esimerkiksi akun impedanssin muutosten hyödyntäminen akun varaustilan ja kuntotilan estimointiin. Lisäksi, menetelmä vaatii ainoastaan kaksi eri signaalitasoa, mikä mahdollistaa menetelmän yksinkertaisen ja edullisen toteutuksen esimerkiksi jo akkujärjestelmässä olemassa olevan akun balansointipiirin yhteyteen. Tässä artikkelissa menetelmästä julkaistut tulokset pohjautuu julkaisuissa [9-10] esiteltyihin tuloksiin ja teoriaan.

Lähteet

[1] J. S. John, "Global energy storage to double 6 times by 2030, matching solars spectacular rise," Bloomberg New Energy Finance (report), 2017.

[2] S. King, N. Boxall, and A. Bhatt, "Lithium battery recycling in Australia - Current status and opportunities for developing a new industry," CSIRO, 2018.

[3] J. Rivera-Barrera, N. Munoz-Galeano, and H.Sarmiento-Maldonado, "SoC Estimation for Lithium-ion Batteries: Review and Future Challenges," Electronics, vol. 6, no. 4, p. 102, 2017.

[4] D. I. Stroe, M. Swierczynski, S. K. Kær, and R. Teodorescu, "Degradation Behavior of Lithium-Ion Batteries During Calendar Ageing - The Case of the Internal Resistance Increase," IEEE Trans. Ind. Appl., vol. 54, no. 1, pp. 517–525, 2018.

[5] J. Vetter, P. Nov, M. R. Wagner, and C. Veit, "Ageing mechanisms in lithium-ion batteries," Journal of Power Sources, vol. 147, pp. 269–281, 2005.

[6] P. Weicker, A system Approach to Lithium-ion Battery management. Artech House, 2013, no. 2013.

[7] M. Berecibar, I. Gandiaga, I. Villarreal, N. Omar, J. Van Mierlo, and P. Van den Bossche, "Critical review of state of health estimation methods of Li-ion batteries for real applications," Renewable and Sustainable Energy Reviews, vol. 56, pp. 572–587, apr 2016.

[8] A. Zenati, P. Desprez, and H. Razik, "Estimation of the SOC and the SOH of Li-ion batteries, by combining impedance measurements with the fuzzy logic inference," IECON Proceedings Industrial Electronics Conference), pp. 1773–1778, 2010.

[9] J. Sihvo, T. Messo, T. Roinila, and R. Luhtala, "Online internal impedance measurements of li-ion battery using prbs broadband excitation and fourier techniques: Methods and injection design," in 2018 International Power Electronics Conference (IPEC-Niigata 2018 -ECCE Asia), May 2018, pp. 2470–2475.

[10] J. Sihvo, T. Messo, T. Roinila, and D. I. Stroe, "Online identification of internal impedance of Li-ion battery cell using ternary-sequence injection,"in Energy Conversion Congress and Exposition (ECCE), 2018 IEEE, 2018, pp. 1–7.

[11] K. Godfrey, Perturbation Signals for System Identification. Prentice Hall, 1994.

[12] R. Al Nazer, V. Cattin, P. Granjon, M. Montaru, M. Ranieri, and V. Heiries, "Classical EIS and square pattern signals comparison based on a well-known reference impedance," World Electric Vehicle Journal, vol. 6, no. 3, pp. 800–806, 2013.

[13] A. J. Fairweather, M. P. Foster, and D. A. Stone, "Battery parameter identification with Pseudo Random Binary Sequence excitation (PRBS)," Journal of Power Sources, vol. 196, no. 22, pp. 9398–9406, 2011.

[14] P. Manganiello, G. Petrone, M. Giannattasio, E. Monmasson, and G. Spagnuolo, "FPGA implementation of the EIS technique for the on-line diagnosis of fuel-cell systems," IEEE International Symposium on Industrial Electronics, 2017.

Jukka Koskinen*, Timo Salmi, Pekka Kilpeläinen, Pertti Lahdenperä

Robotiikan mahdollisuudet rakentamisessa

Avainsanat: robotiikka, automatisointi, rakentaminen

***Jukka Koskinen:** VTT Oy, PL 1000, 0244 VTT, jukka.koskinen@jvtt.fi

Muut kirjoittajat: Timo Salmi, Pekka Kilpeläinen, Pekka Lahdenperä, VTT Oy, PL 1000, 0244 VTT, etunimi.sukunimi@vtt.fi

Tiivistelmä: Rakentamisessa tuottavuuden kasvu on ollut heikompaa kuin esimerkiksi konepajateollisuudessa, jossa on tapahtunut huomattavasti isompi tuottavuuden kasvu tuotantoprosessien digitalisoinnilla, robotisoinnilla ja kehittyneillä työstökoneilla. Varsinainen rakentamistyö tehdään yhä pääsoin perinteisin menetelmin, tosin digitalisoituja suunnitelmia hyödynnetään. Automatisoituja koneita ja laitteita rakennustyömailla ei ole juurikaan voitu hyödyntää samalla tavalla kuin konepajateollisuudessa. Automatisoinnin esteinä ovat mm. rakennusten yksilöllisyys, lyhyet työvaiheet, isot materiaalivirrat, matala käyttöaste yksittäisellä laitteella, epätarkat suunnitelmat automatisoinnin kannalta ja ahtaat tilat laitteiden siirtämiseen.

Rakentamisessa on kuitenkin paljon matalaa osaamista vaativia ja työolosuhteiltaan haastavia tehtäviä, kuten esim. poraus, hionta, vanhan materiaalin poisto, tavaroiden kuljetus. Näissä on nähtävissä potentiaalia hillitä rakentamiskustannusten nousua robotiikan avulla.

Rakentamisessa tarvittavien komponenttien, kuten esimerkiksi katto- ja seinäelementtien, valmistamisessa automaattisia laitteita käytetään ja myös robotteja on voitu hyödyntää. Rakentamisen robotisoinnin kannalta haasteet ovat hyvinkin erilaiset eri rakentamisvaiheissa (perustus-, runko- ja ulkotyöt, sisärakenteet, LVIS-työt). Lisäksi erilaiset rakennustavat asettavat omat haasteensa (puu- ja betonielementtitalot, tiilitalot, hirsitalot). Rakentamisen perinteet ja rakentamismääräykset ovat eri maissa hyvinkin paljon toisistaan poikkeavia, mikä on omalta osaltaan hankaloittanut rakentamisen menetelmien ja laitteiden kehittämistyötä. Monissa maissa edullinen työvoima on aikaisemmin ollut rakennuttajalle parempi ja joustavampi vaihtoehto kuin automatisoiduit laitteet.

Elementtiteollisuutta lukuunottamatta kaupallisiksi tuotteiksi asti kehitettyjä automaattisia laitteita tai järjestelmiä on vähän markkinoilla ja varsinaista läpilyöntiä eli laajamittaista käyttöönottoa ei ole minkään sovelluksen osalta vielä tapahtunut. Haaste onkin löytää robotiikalle ne käyttökohteet, jotka mahdollistavat uuden liiketoiminnan luomisen ja kehittämisen. Rakentamisalalla on nähtävissä tilaa uusille robotiikkaa ja automaatiota hyödyntäville innovaatioille.

Tässä tutkimuksessa selvitettiin analysoimalla lähes kaikki rakentamisen työtehtävät. Analyysien perusteella tunnistettiin potentiaalisia robotisointikohteita, jotka otettiin tarkempaan tarkasteluun. Valitulle työtehtäville tehtiin karkeat ratkaisumallit ja kustannuslaskelmat, joiden avulla arvioitiin robotisoinnin kannattavuutta valituissa työlajeissa. Näiden perusteella tunnistetiin toiminnan kannalta kriittisiä toimintoja. Arvioimme, että monessa tapauksessa robotisoinnin hinta on liian kallis huomioiden robotin alhainen käyttöaste rakentamisessa. Robotin tulisi olla siten monikäyttöisempi, että se kiinnostaisi rakentajia. Elementtitehtailla tehtävät valittiin tehtailla tehtyjen haastattelujen perusteella.

Igor Trotskii*, **Jukka Pulkkinen**

Unsupervised machine learning model for heat flow monitoring in a geothermal energy storage in a near-zero-energy building

Igor Trotskii: Häme University of Applied Sciences, E-mail: igor.trotskii@hamk.fi

Jukka Pulkkinen: Häme University of Applied Sciences, E-mail: jukka.pulkkinen@hamk.fi

Keyword: Condition Based Maintenance, principal component analysis, near-zero-energy building, process monitoring

Extended abstract. With a fast-paced development in IoT, information processing and process monitoring techniques, building automation systems become more and more complex and advanced. Evolution of these technologies allows to greatly improve buildings' energy performance and substantially decrease maintenance costs by utilizing such ideas as Condition Based Maintenance (CBM) and Machine Learning, which CBM heavily relies on. As most of the buildings are still maintained through normal means, such as reactive and schedule-based maintenance, because of lack of property managers' interest in investing in more efficient approaches, this paper's aim is to cover this gap by providing short overview of most basic machine learning and data processing algorithms used in building maintenance domain and by providing case study results.

CBM has been an interesting topic since long ago as it allows to greatly reduce downtime of the process without the need for frequent equipment checks and replacements as scheduled maintenance dictates. However, CBM adoption is limited by high initial costs as it requires modern equipment with embedded self-diagnostic capabilities. On the other side, Internet of Things has been developing rapidly, bringing the ease of obtaining enormous amount of data from monitored process without big investment costs. This makes it possible to utilize measurement data in conjunction with machine learning and statistical techniques to build relatively inexpensive CBM systems, avoiding costly investments into new equipment by moving part of expenses to the software for monitoring and analyzing process parameters which can be easily measured, but have indirect impact on the state of the monitored process.

The main purpose of this study is to determine possible data analytics techniques to utilize in building maintenance domain in a case with limited amount of data. Event though, many algorithms for fault detection and anomaly detection are already presents, the selection of a proper techniques and their application in building maintenance domain is still hard, due to limited amount of the research and available data.

The study was conducted using process data from Sheet Metal Center industrial hall building in Visamäki, Hämeenlinna, which is a near-zero-energy building with a complex automation system. The data collected from the process was analyzed with principal component analysis and then used for locating anomalies in the process by utilizing Hotelling's T^2 and SPE statistics. The results were carefully verified with the help from experts closely familiar with process nature and k-means clustering, which was used to evaluate the state of the studied system.

Petri Hietaharju*, **Mika Ruusunen**

Forecasting and optimization of the heat demand at city level

Abstract: Computational methods have been developed for the predictive optimization of the heat demand to increase energy efficiency in heating by taking into account the point of view of both the energy producers and consumers. Research methods included the modelling of the individual buildings indoor temperature and heat demand, which can then be expanded to a larger scale to optimize the heat demand at the city level. The developed models are accurate and easily adaptable enabling the city level predictive optimization of the heat demand. This makes it possible to better adapt to and prepare for future changes in the outdoor temperature while at the same time ensuring the normal living conditions and optimized energy efficiency, also enabling the demand side management in the heating network. However, the full realization of the concept requires proper real-time and two-way information flow through the whole energy chain.

Keywords: district heating, modelling, prediction, demand side management, optimization

***Petri Hietaharju:** Control Engineering, Environmental and Chemical Engineering, University of Oulu, E-mail: petri.hietaharju@oulu.fi

Mika Ruusunen: Control Engineering, Environmental and Chemical Engineering, University of Oulu, E-mail: mika.ruusunen@oulu.fi

Introduction

Energy Efficiency Directive (EED) sets binding measures for EU countries to improve energy efficiency. At the same time, buildings represent 20–40% of the total energy consumption. Furthermore, for 15 of the 28 EU countries the annual heat demand in buildings presents the largest energy demand. For the aforementioned reasons, the implementation of new energy efficiency measures for the heating and building sectors is of utmost importance.

As the requirements for energy efficiency are becoming stricter, buildings cannot be considered as isolated elements in energy systems when developing new control and optimization schemes for district heating systems. A concept for optimizing the heat demand in district heating systems has been proposed by the authors (Figure 1) [1]. The concept approaches the subject by predicting the heat demand and then optimizing the heat production utilizing demand side management (DSM). However, city level consumption forecasts can be extremely time-consuming if the simulations are done on a single building level. Consequently, forecast models are widely used for individual buildings, but their application at the large scale is lacking. Ease of modelling would make the forecasting of heat demand and the implementation of predictive control strategies at the building and city level more cost-effective. In this regard, the applied models have to be easily reproducible for multiple buildings. This sets requirements for the simplicity and ease of parametrization of the models. The straightforward implementation in real applications should also be kept in mind. In modern automation, the cost of implementation work plays a key role while the cost of the hardware is decreasing.

Forecasting models

Straightforward modelling methods would enable DMS to be implemented at city level. When optimizing the heat demand utilizing DSM, maintaining the indoor temperature at an acceptable level in buildings is important as the control actions should ensure the quality of the living conditions.

For wide use of any indoor temperature or heat demand model, it should be applicable to different types of buildings with minimum extra implementation work. A new dynamic modelling approach was developed to predict and optimize the indoor temperature in large buildings [2]. The average relative modelling error of the developed model was below 5%. Two different straightforward modelling approaches were developed to forecast the hourly heat demand at city level considering more than 4000 individual buildings [3]. The relative error was 4% for the city level heat demand forecast. Low amount of estimated parameters reduced the calculation time and easily attainable measurement data facilitates the

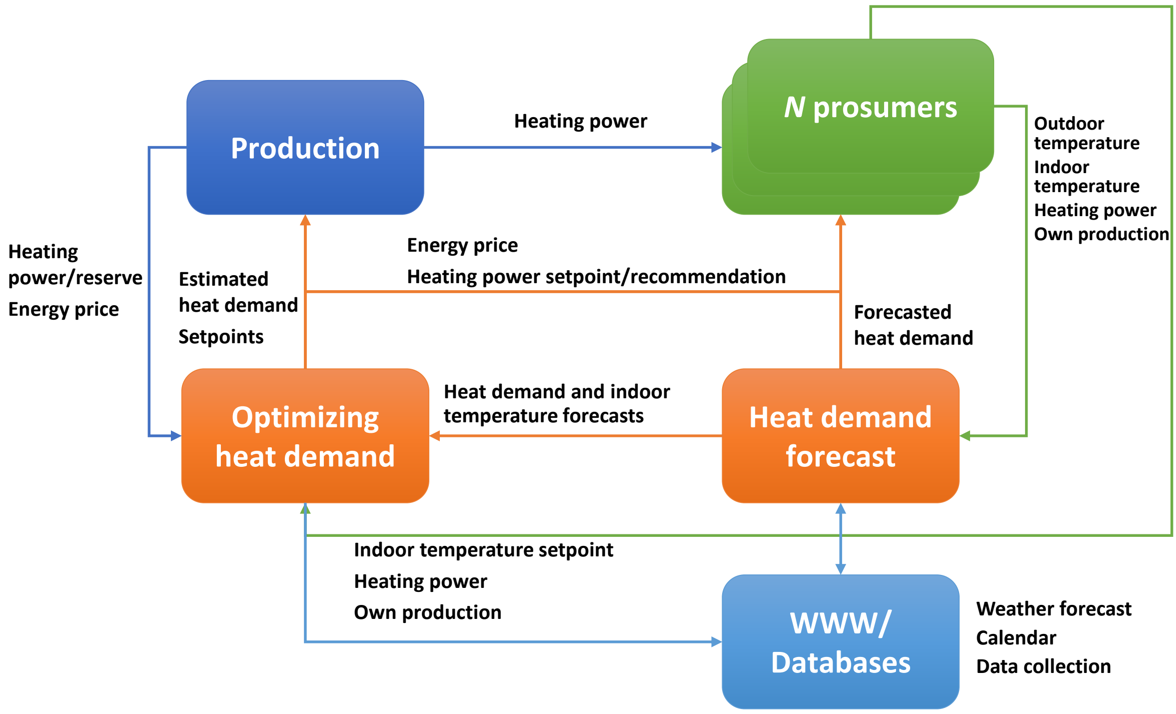


Figure 1. Concept for the predictive optimization of the heat demand.

implementation of the models for thousands of buildings.

Optimization

Heat demand forecast based on the forecasted heat demand of individual buildings together with the information on the indoor temperature of the buildings would enable different DSM action. These include peak load cutting, the minimization of the heat demand and timing of the energy production.

Peak loads refer to times of high energy consumption. The heat demand forecast would be used to identify these peak loads before they happen and the thermal mass of the buildings could be used to cut them. Simulations of different peak load cutting scenarios have been performed in two apartment buildings by utilizing the developed indoor temperature model [4]. The results showed that the studied buildings had very different heat storage capacities and that the system level effect of peak load cutting cannot be concluded based on the results of a single building.

Optimization strategy that would have direct benefit for the building owners would be the minimization of the heat demand. Preliminary results from a field test, where the optimization of the heat demand was performed in a school building, showed that significant savings in heat consumption and reduction in peak loads are possible [1].

The timing of energy production refers to the timing of electricity production in combined heat and power (CHP) plants. At favorable times, electricity production could be increased and the extra heat could be stored in the buildings.

All the aforementioned predictive optimization strategies would utilize buildings as short term heat storages. As the heat storage capacity of buildings is already existing, only proper ways to utilize it are needed. The easily adaptable models would enable the application of the predictive optimization methods to the whole building stock providing predictive information on the heat demand and indoor temperature in buildings. However, the full realization of the concept would require proper real-time and two-way information flow through the whole energy chain.

References

[1] Hietaharju P., Ruusunen M., A concept for cutting peak loads in district heating, Proceedings of the Automaatio XXI, Helsinki, Finland, 17–18 March 2015

[2] Hietaharju P., Ruusunen M., Leiviskä K., A Dynamic Model for Indoor Temperature Prediction in Buildings, Energies, 2018, 11, 1477, DOI: 10.3390/en11061477

[3] Hietaharju P., Ruusunen M., Leiviskä K., Enabling Demand Side Management: Heat Demand Forecasting at City Level, Materials, 2019, 12, 202, DOI: 10.3390/ma12020202

[4] Hietaharju P., Ruusunen M., Peak Load Cutting in District Heating Network, Proceedings of the 9th EUROSIM Congress on Modelling and Simulation, Oulu, Finland, 12–16 September 2016

Dat Huynh*, Sy Nguyen*

Engaging building automation data visualization using Building Information Modelling and Progressive Web Application

Extended abstract: This paper presents a framework for efficient development an interoperable visualisation of a building digital model through an intuitive interface, for the improvement of the Building Lifecycle Management (BLM). The framework implemented as a case study, where multiple rich visualisations of buildings in Kanta-Häme region were constructed using their construction floorplans and building automation data. “Digital Twin”, in the scope of building automation development, is a concept related to a physical structure’s digital representative carrying real-time properties of the original copy, and thus, the implementation of such is considered to be beneficial and to gradually raise the premise’s asset value in terms of operation. In the BLM process, different tasks such as ambient conditions monitoring, maintenance, occupant feedback collection etc., are necessary and would be labour intensive without proper use of digitalization and ICT. Therefore, having an effective building visualisation utilising the ‘Digital Twin’ principle would deliver a significant improvement on the BLM process, ensuring the effectiveness benefits achieved by automation processes. Nevertheless, to effectively deliver key insights from the collection of data as an accurate reflection of a building, a need for a systematic approach to the development of a meaningful and engaging visualisation is raised.

The aforementioned approach could be accomplished first by creating a digital model from the Building Information Modelling (BIM) process. BIM offers a global view and an integrative collaboration of a construction project, both in pre- and post-occupancy period. In other words, BIM is a multi-disciplinary combination of various shareholders, e.g. architecture, engineering, construction and operation (AECO). Three-dimensional (3D) models of occupied buildings usually require their latest two-dimensional (2D) drawings, i.e. from renovation or modernisation, from architectural to structural, from its surroundings to its interior organization, etc. However, in many cases those documents are not all available, and, as more information is given, the more detailed the model can be. For constructing a minimal BIM model, at least the floorplan, elevation, and cross-section drawings are needed, following which the model can be utilised for different purposes. For example, BIM applications in simulation and visualisation have been proven to be versatile in the era of digitalisation - where fragmentation in information collection is minimised and multi-purposed optimisation enables the improvement building performances.

After a successful BIM process, the building model and its data can then be utilised for constructing a user interface as a “Progressive Web Application” (PWA). The term refers to a fast, reliable, and engaging web application (app). In other words, this app is expected to function and perform reliably across multiple devices to provide an enhanced user experience for better engagement/ re-engagement, without being affected by poor network conditions. For this reason, web-based applications’ competence level has increased in recent years against their native, desktop counterparts. At a consumer level, the JavaScript React framework was chosen for the development process for its built-in flexibility. The interface application was then developed; the building data was filtered and organised in a user-oriented manner. It is worth noticing, that without the help of the Internet of Things (IoT) technology, this web-based application approach would have become much more challenging and even impossible. Modern IoT sensors and communication protocols development has allowed more reliable and accurate measurements in variant fields, resulting in the enhancement of building metric collection. In addition, the usage of protocol combination such as OPC-DA, OPC-UA and MQTT provides a standard to ensure a seamless connection between the web and various arbitrary devices from different providers.

The case study involved the visualisations of two buildings in Hämeenlinna city, one of which already had an extensive model and the other only had floorplan drawings. Different indoor conditions were measured and collected from the building automation system and additionally installed sensors. In the preliminary stages,

essential building data such as temperature, humidity level, CO_2 level, etc. were collected. By constructing engaging interfaces, building-related data was successfully displayed, while constant feedback from buildings' occupants and operators were gathered to improve the application further. Future developments include enhancement of the user interface to ensure a natural user experience (UX) and deep automation of the process to systematically generate the PWA from data model and building architecture collection.

Keywords: Progressive Web Application, Building Information Modelling, Building Lifecycle Management, Simulation, Visualisation.

***Corresponding Author:**

Dat Huynh: Häme University of Applied Sciences, E-mail: dat.huynh@student.hamk.fi

Sy Nguyen: Häme University of Applied Sciences, E-mail: sy.nguyen@student.hamk.fi

Ekaterina Nikolskaya, Mika Liukkonen, Yrjö Hiltunen*

Real-time measurement system for determining metal concentrations in water-intensive processes

Keywords: Mining water, precipitation, metal concentration, NMR, Time domain.

***Corresponding Author: Yrjö Hiltunen:** University of Eastern Finland, P.O. Box 1627, FIN–70211 Kuopio, Finland, E-mail: yrjo.hiltunen@uef.fi

Ekaterina Nikolskaya, FiberLaboratory, South-Eastern Finland University of Applied Sciences, Savonlinna, Finland

Mika Liukkonen: University Of Eastern Finland, Kuopio, Finland

1 Background

Tightening requirements for the environmental quality of mining and process waters require more efficient purification methods. However, today's commercially available water quality measurements are not able to cope with certain significant contaminants like metal and sulfate concentrations in real time. In addition, presently used water quality monitoring systems require regular maintenance and calibration, which reduces their cost-efficiency.

High-resolution nuclear magnetic resonance (NMR) spectroscopy is one of the most informative analytical method in chemistry, but it is difficult to apply it to online process control in practice. Time domain nuclear magnetic resonance method (TD-NMR) is becoming highly attractive for industrial applications due to relatively low price, mobility, easy operating, and simple sample preparation procedure.

2 Aims

In this paper, the TD-NMR technology has been utilized for monitoring the concentrations of metal ions in water-based solutions. The main focus has been on paramagnetic ions such as Mn^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, Zn^{2+} and Ni^{2+}, which are the principal metal components in mining waters. Different concentrations of single metals and mixtures of them, and real mining water samples have been used in the tests.

3 Materials and methods

TD-NMR is sensitive to the presence of paramagnetic ions, which makes it a potentially applicable technology for measuring metal concentrations in mining waters.

The relaxivity of metal ion reflects how the relaxation rates of a solution change as a function of concentration [C]. Since a metal ion may affect the two relaxation rates (R_1 and R_2) individually, there are two corresponding relaxivities, denoted by r_1 and r_2. By definition

$R_1 = r_1 \bullet [C] + \text{constant1}$, and

$R2 = r2 \bullet [C] + \text{constant2}$

Since R_1 and R_2 are given in seconds-1 and [C] is measured in milligrams per liter, r_1 and r_2 have the units of l/mg s. Relaxivity depends on the temperature, field strength, and the substance within which the metal ion is dissolved.

4 Results

4.1 Single metals

In this paper, we have focused on the relaxation rate R_2, and the relaxivities r_2 for several metal ions are determined. The results are presented in Table 1. It can be summarized that the measurement of the concentrations of single metals is very accurate in laboratory conditions.

To simulate the effect of metal precipitation, some laboratory measurements were conducted. In these tests, the relaxation rates R_2 of Fe^{3+} were measured as a function of the pH. The pH of the solution was increased by adding some sodium hydroxide (NaOH). The initial concentration of ions was 40 mg/l at pH 1. The concentrations of Fe^{3+} were then calculated by using R_2 and r_2 values (See r_2 value in Table 1.). The calculated concentrations of Fe^{3+} as a function of pH are shown in Figure 1.

Table 1. Relaxivities r_2 for metal ions obtained in water solution by TD-NMR. Figures in parentheses show the errors of the relaxivities.

Metal ion	Relaxivity r_2 (l/mg s)
Mn^{2+}	0.81765(226)
Fe^{3+}	0.28799(365)
Fe^{2+}	0.01194(1)
Cu^{2+} ($CuSO_4$)	0.01493(10)
Cu^{2+} ($CuCl_2$)	0.01443(14)
Ni^{2+}	0.01239(9)
Zn^{2+}	0.00069(1)

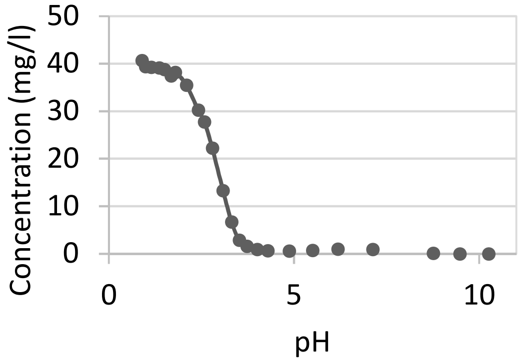


Figure 1: Fe^{3+} concentration as a function of the pH, calculated by R_2 measurements and the relaxivity presented in Table 1.

4.2 Mixtures of metal ions

In real-world conditions, metals in waters typically exist in mixtures of several metal components. Therefore, a real mining water sample was also measured as a function of pH. These experimental relaxation rates of the water can be seen in Figure 2 ("Experimental"). The Mn, Fe, Cu and Zn concentrations of the samples were also measured by the x-ray fluorescence (XRF) method. Using these concentration values and the relaxivities presented in Table 1, the corresponding relaxation rates were calculated (Figure 2; "Calculated"). In addition, the concentrations of the metal ions were estimated by means of the ChemEQL software (https://www.eawag.ch/en/ department/surf/projects /chemeql/), which is a computer program for calculating chemical speciation equilibria. Again, using these and r_2 values, the relaxation rates were calculated (Figure 2; "Theoretical"). As can be seen, all these different determinations are in a relatively good agreement with each other.

5 Conclusions

A real-time measurement system for determining metal concentrations in water-intensive processes was demonstrated in this study. The system includes a measurement device based on NMR technology, additional technology for transferring samples and controlling measurement conditions, the necessary software technology, protection housing, and cabling. These parts form the so called intelligent measurement system, which makes it possible to manage water processes and their metal concentrations better.

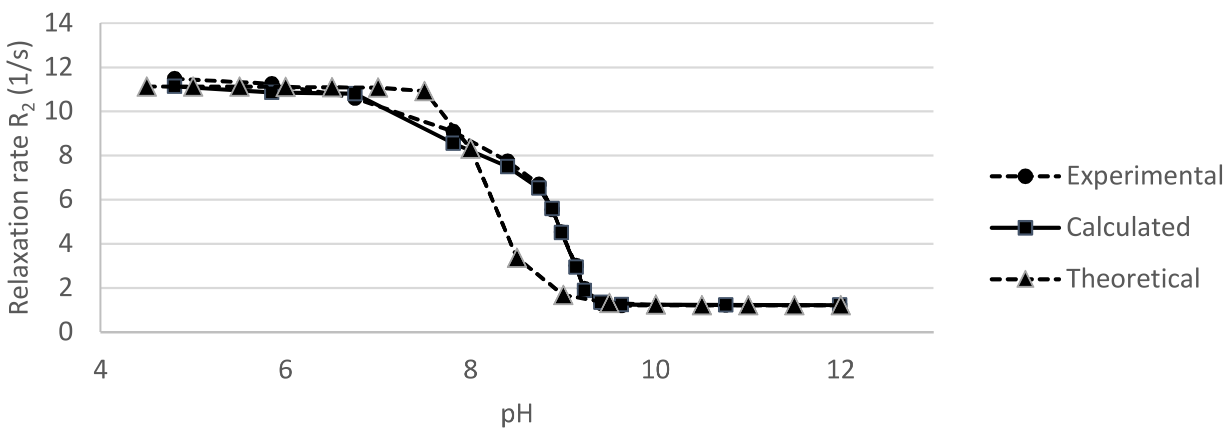


Figure 2: Independent components using the data contaminated by 0.5% of random failures.

Kai Zenger*, Nguyen Khac Hoang

Optimal control maps for fuel efficiency and emissions reduction in maritime diesel engines

Abstract: The paper introduces an advanced modelling method and optimisation algorithm, by which ship diesel engines control parameters can be effectively designed. The fuel consumtion is minimised while at the same time fulfilling the NO_x emission constraints. The problem is non-trivial: the methodology introduced proves efficient, is fair and fulfils the regulations set by the International Maritime Organisation.

Keywords: diesel engine, NOx emissions, fuel efficiency, control map, optimisation, optimal design

***Corresponding Author: Kai Zenger:** Aalto University, School of Electrical Engineering, E-mail: kai.zenger@aalto.fi
Nguyen Khac Hoang: Aalto University, School of Electrical Engineering, E-mail: hoang.kh.nguyen@aalto.fi

Extended abstract. Oceangoing ships are the largest single cause of nitrogen oxides (NOx) emissions globally, and NOx is generally a major air pollutant in the atmosphere. Most of these emissions are released near the land, which causes a ma-jor pollutation problem and health risk to the people. It has been reported that outdoor air pollutation caused about three million premature deaths globally in 2010. Since ship transportation is constantly increasing, it is easy to understand that the International Maritime Organization (IMO) is setting more and more stringent restrictions to ship emissions. Large tankers are major pollutants driven by diesel engines. Even if the number of diesel engines in automobile industry is foreseen to decrease fast in the future, such a trend cannot be foreseen for maritime engines, because replacement of large diesel engines as power source in maritime applications seems to be a hopeless task for several decennia to come.

The engine manufacturers are interested in developing more and more efficient engines with increasing efficiency, reduced fuel consumption and redured emissions. Unfortunately, considerable efficiency increase is already hard to establish, and reducing fuel consumption generally implies higher NOx emissions and vice versa. Because of this, IMO has set regulations (Tier II and Tier III) that set limits to NOx emissions in some operation points (speed and load) of the ship. However, only a few operation points have been set, which means that it is unclear how the ship emissions should be controlled over the whole operation range. Even worse, the current regulations give a possibility to “cheat” by setting the emissions low at the given operation points (high fuel consumption) but use all effort to save fuel in other operation points (high NOx emissions). The paper presents a method, where the Design of Experiments (DOE) method is used to model the fuel consumption and NOx emission at any given operation point. It then becomes possible to construct smooth functions to cover all operation points of the ship engine. At any operation point an optimization problem can be set and solved, where the fuel consumption is minimized under a given constraint of maximum NOx emission. The solution gives certain control parameters of the ship (common rail pressure, charge air pressure, start of ignition timing), which are to be used in the operation point in question for optimal performance. It now becomes possible to compare the fuel consumption and emission level under standard routes travelled by the ship. In addition to that it becomes possible to construct optimal operation parameters and allowed NOx levels under a large number of operation points, thus giving advice to IMO how te future regulations could be stated, in order to cover all operational areas and to avoid all possibility to cheat. The results of the paper have been obtained and confirmed using real diesel engine data from large engine manufacturers.

References

[1] L. Guzzella and A. Amstutz. Control of diesel engines. *IEEE Control Systems*, 18(5):53–71, 1998.
[2] J. B. Heywood. *Internal Combustion Engine Fundamentals*. Mc-Graw-Hill, 1988.
[3] H. N. Khac and K. Zenger. Designing optimal control maps for diesel engines for high efficiency and emission reduction. European Control Association, 2019. (to appear).
[4] Imo marine engine regulations. *Emission Standards*. URL https://www.dieselnet.com/standards/inter/imo.php.

Arto Visala*, Panu Harmo, Janne Luukkaa, Mirja Salkinoja-Salonen, Jorma Selkäinaho

New IoT connected sensors to detect indoor air pollutants

Extended abstract. Current indoor air quality measurement systems very often fail to find causes for building related health issues. New measurements need to be developed to detect pollutants and their sources. Internet of Things techniques give new cost effective tools for this work.

Our experiments show that humidity can carry pollutants even when the pollutant itself is non-volatile.[1] By analysing the surface tension of water condensed from indoor air we can detect possible problem sources. A real time humidity condensing and water tension measurement system was developed using internet connected microcontrollers and cloud services [2]. Laboratory experiments were performed in glass chambers equipped with humidifiers, water vapour condensers, and sensors for temperature, humidity, total volatile organic compounds (TVOC), and water surface tension. It was shown that large size, non-volatile wetting agent molecules used in cleaning products (Genapol X080) can be detected in the chamber air using TVOC sensors. The surface tension of the condensed water also changed, when Genapol was added to the bottom of the measurement chamber. Condensed water samples were further tested for toxic effects in human cells and analysed using capillary electrophoresis to characterise the pollutants.

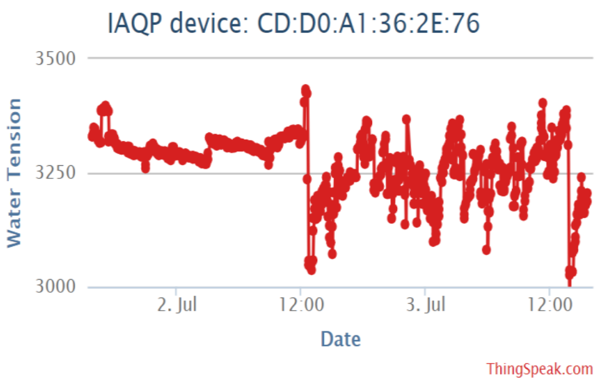


Figure 1. The graph from cloud service shows how the surface tension of chamber air water vapour condensate was affected by placing of a Genapol X080 containing tray onto the chamber floor at 12.39 o'clock.

Hydrogen sulphide and other sulphides are harmful even in small concentrations. They can be introduced to indoor air from drains and plaster materials damaged by moisture, for example. Air borne sulphides tarnish silver. The tarnish on silver is measured with RGB-sensors to discover sulphide contaminations [3]. Using the developed IoT measurement system cumulative effect of sulphides in darkening the surface of silver was measured. The real time cumulative effect, the darkening of the silver surface, is visualised in real time using ThingSpeak cloud service.

Both Internet based methods enable detecting and eliminating indoor air problems even before they cause harm to people.

Keywords: Internet of Things, Indoor Air Quality, humidity, condensation, surface tension.

***Corresponding Author: Arto Visala:** Aalto University, Department of Electrical Engineering and Automation, E-mail: arto.visala@aalto.fi

References

[1] Selkäinaho J., Harmo P., Salkinoja-Salonen M., Luukkaa J., Siren H., Riekkola M-L, Andersson M., Mikkola R., Salonen H., Kurnitski J. and Visala A., Water vapour mobilises building related non-volatile chemicals and mycotoxins and may be used to remove substances of potential health hazard from indoor surfaces, Roomvent & Ventilation 2018 Proceedings, (ISBN 978-952-5236-48-4)

[2] Luukkaa J., Surfactant detecting wireless sensor cloud, Master's Thesis, Aalto University, Espoo, Finland, 31.7.2018

[3] Harmo, P, Puusa, J, Lehtinen, S, Selkäinaho, J, Aattela, E, Visala; A ja Salkinoja-Salonen, M, Mikrobien tuottamat haitalliset rikkiyhdisteet sisäilmassa: uusi on-line sovellettava mittaustekniikka, Sisäilmastoseminaari 2017, pp. 233-238, Helsinki, Finland, 15/03/2017.

Heli Karaila*, Lasse Järvinen, Ari Oksanen

Mass flow-based controls with solids measurements reduce sludge handling costs

Extended abstract. The Tampere Water Viinikanlahti wastewater treatment plant in Tampere, Finland has commissioned what is believed to be the world's first multi-variable predictive controller (MPC) of a centrifuge sludge dewatering operation based on multiple online measurements of solids content. The online measurements replace manual testing that was considered too slow or not timely enough for optimum real time control. The objective was to avoid wasting energy and chemicals and save on dry cake disposal costs. The centrifuge mass flow-based control is part of a strategy by the Viinikanlahti plant to equip the treatment plant with total solids measurement to control and optimize other unit operations based on mass flow values rather than volumetric values. These include total solids-based primary clarifier sludge pump scheduling and anaerobic digester input solids optimization.

In the centrifuge operation the dry cake solids and the recycled centrate suspended solids are functions of several variables which interact with each other. It is therefore an application for multi-variable process control (MPC) which has been implemented in a small control system. The online measurements involved in the centrifuge control are feed solids, dry cake solids as it falls to the conveyor and centrate suspended solids. Polymer flow and centrifuge torque are also inputs. The responses of controlled and manipulated variables determined online are input to a control matrix which makes the best control decisions to achieve the desired results.

The objectives of the control are to produce a dry cake with solids content as high as possible to reduce transportation costs by truck, to minimize recirculated centrate dissolved solids that would increase polymer and dewatering costs, and to minimize polymer consumption. The paper presents the results of the control implementation which include a 50% reduction in centrate solids and a 1% to 2% increase in dry cake solids. The impact of these changes on chemical consumption is being evaluated and the results to date will be presented. The operators have confidence in the control and use it continuously. They have more time for other controls and tasks. One operator takes care of the entire plant during evening and night shifts and weekends. Also, to reduce costs the plant staff is making plans to reduce manual testing frequency.

With solids measurement after the primary clarifiers the pumping sequence from the clarifiers is now controlled to minimum solids content. The primary sludge consistency has been increased and the water load substantially decreased, thus avoiding excess water being pumped to sludge thickening and excess pumping energy as was the case with time-based control. With another total solids measurement after thickening, the optimized solids level to the anaerobic digester is expected to reduce the heating demand, reduce foam generation and increase biogas production. The results of these controls are presented.

Keywords: wastewater, centrifuge, dewatering, optimization, MPC

***Corresponding Author:** Business manager Heli Karaila, E-mail: heli.karaila@valmet.com

Co-authors: Lasse Järvinen lasse.jarvinen@tampere.fi, Ari Oksanen ari.oksanen@tampere.fi

Mika Ruusunen*, Kauko Leiviskä

Professorship in Biorefinery Measurements

Keywords: biorefinery, on-line measurements, bio-based materials, bioproducts, sensor fusion

***Mika Ruusunen:** Control Engineering, Environmental and Chemical Engineering, University of Oulu, P.O. Box 4300, 90014 Oulu, Finland, E-mail: mika.ruusunen@oulu.fi.

Kauko Leiviskä: Control Engineering, Environmental and Chemical Engineering, University of Oulu, P.O. Box 4300, 90014 Oulu, Finland, E-mail: kauko.leiviska@oulu.fi

1 Background

The Faculty of Technology at the University of Oulu, Oulu, and the Kajaani University Consortium, Kajaani, have launched a full professorship position in Biorefinery measurement. This five-year post strengthens the focus area 'Creating Sustainability through Materials and Systems' of the University of Oulu. The professorship is located in Kajaani and Oulu. It is a part of the Faculty of Technology and Control Engineering Research unit at the University of Oulu. The other financiers of the Professorship together with the University are Kajaani City, Kainuun Liitto, St1 and Valmet. The work takes place both in Kajaani and Oulu campuses. A research group of 3 – 4 researchers will support Professor Mika Ruusunen.

2 Research focus

The field of the Professorship focuses on on-line measurements in production processes of bio-based industries, especially in areas related to biochemistry of wood and wood-based materials. The main areas of the research include

- Analysis and measurements in modern biorefinery, its side streams and side products,
- Optimizing/optimal control of these production processes also from the biochemical viewpoint and the role of measurement technologies in there,
- Measurement needs coming from authorities: environmental permits, safety issues,
- Research on the future replacement of existing off-line and laboratory technologies with reliable on-line measurements.

Many of the present processing issues in the content of biorefinery concepts are due to variation in quality of biomass feedstock and its other properties. There, new measurement technologies can enable plant-wide compensation strategies for these issues. For this, research aims to develop reliable and predictive on-line measurements of the key variables for biorefinery processes. This includes then systematic process identification, designed laboratory experiments, and field tests for exploring process interactions and dynamics as a plant wide.

The reliability and traceability of the on-line measurements plays an increasingly important role. On the other hand, existing and novel measurement principles or technologies may require new (re)-calibration and continuous performance assessment methods in order to be implemented to automation system and to function properly. Moreover, methods to validate and maintain whole measurement system need to study further. Then, on-line measurement uncertainty estimation and self-validation development, both with hardware and software based measurements, are of importance.

3 Results

The first active research topics relate to the remote measurements and control of distributed bio-product mills processing organic residues. In addition, a novel principle for real-time estimation of moisture content in sawdust has been explored (paper 36: On-line moisture content estimation of saw dust via machine vision, Authors: Art Valta, Mika Ruusunen and Kauko Leiviskä).

The research history has shown that a proper implementation of new measurement systems requires close collaboration also between the authorities and companies. This calls for co-operation with accredited measurement laboratories (reference measurements) and authorities (legislation, accreditation).

Mika Liukkonen, Jukka Silvennoinen, Yrjö Hiltunen*

Machine learning tools for analyzing the quality of fiber-based corrugated medium

Keywords: Fluting, corrugated medium, modelling, self-organizing map

*Corresponding Author: Yrjö Hiltunen: University of Eastern Finland, P.O. Box 1627, FIN–70211 Kuopio, Finland, E-mail: yrjo.hiltunen@uef.fi

Jukka Silvennoinen: Mondi Powerflute Oy, Kuopio, Finland

Mika Liukkonen: University of Eastern Finland

1 Background

Modelling of processes in the wood processing industry is challenging for several reasons. For example, in certain cases it is important that the models are functional in real time or almost real time conditions when it comes to fast decision-making. Process dynamics typically makes it necessary for the models to be able to adapt to dynamically appearing fluctuations and condition changes. Manufacturing of corrugated medium, or fluting, is a good example of a dynamical, complex manufacturing process within the wood processing industry. The fluting manufacturing process involves numerous sub-processes which are typically in mutual interaction and which are controlled by many control loops, which complicates the understanding of the mutual reactions within the total process.

2 Aims

In this paper, we demonstrate how modelling tools may be useful in actions for process improvement by facilitating data analysis and process development work. We validate the selected modelling techniques by analyzing a data set acquired from a real manufacturing process.

3 Materials and methods

3.1 Case study

We have selected an ammonium sulfite based process for manufacturing SemiChemical fluting (NSSC, neutral sulfite semi chemical) for a case study. In this process, wood is first softened in a relatively fast cooking stage. After this, the medium is refined in three stages to get a type of pulp that is the most suitable for the manufacturing of fluting.

The experimental data used in this study were extracted from the databases of the SemiChemical fluting manufacturing plant. The produced fiber-based fluting medium serves as a partition that separates the liners in corrugated board.

3.2 Adaptive models

A single model based on a large data set may not be effective enough in a dynamical manufacturing process. For example, the model may not be accurate enough to catch periodically occurring phenomena. The time of year is a good example of this. In wood processing, the quality of the raw material is highly dependent on the time of year when the wood is cropped. For this reason, it is preferable to use an adaptive model structure, which means that the model will be designed to adapt to changing conditions in the course of time.

It is characteristic for almost all industrial environments that there are a large number of conducted measurements, and therefore measured variables, involved. Due to this, it is not always clear which variables should be included to the model to achieve the best possible result. In addition, the variables that give the best result in modelling may not remain the same all the time. One solution to this would be an algorithm that is based on the sample-wise moving window approach [1]. In practice, one way of applying this would be to create a new model regularly or even every time the model is called (for example, when a predicted value is desired).

3.3 Subtraction analysis

The self-organizing map (SOM) [2] is an unsupervised neural network that is based on mapping n-dimensional input vectors to structural units called neurons, which are formed and updated during the training. Each neuron is characterized by a specific reference vector, which represents the typical features of the data associated with the neuron concerned.

In the subtraction analysis, two vectors are subtracted from each other in order to extract the differences between these vectors [3]. By means of the center (i.e., average) vectors of two given areas on the SOM, the following formula can be used:

$$s = C_\alpha - C_\beta,$$

where s is the subtracted result vector, C_α symbolizes the center vector of area α, and C_β denotes the center vector of area β. This technique can reveal the differences between two differently behaving process conditions. An example of applying the subtraction analysis in the fluting case can be seen in Figure 1.

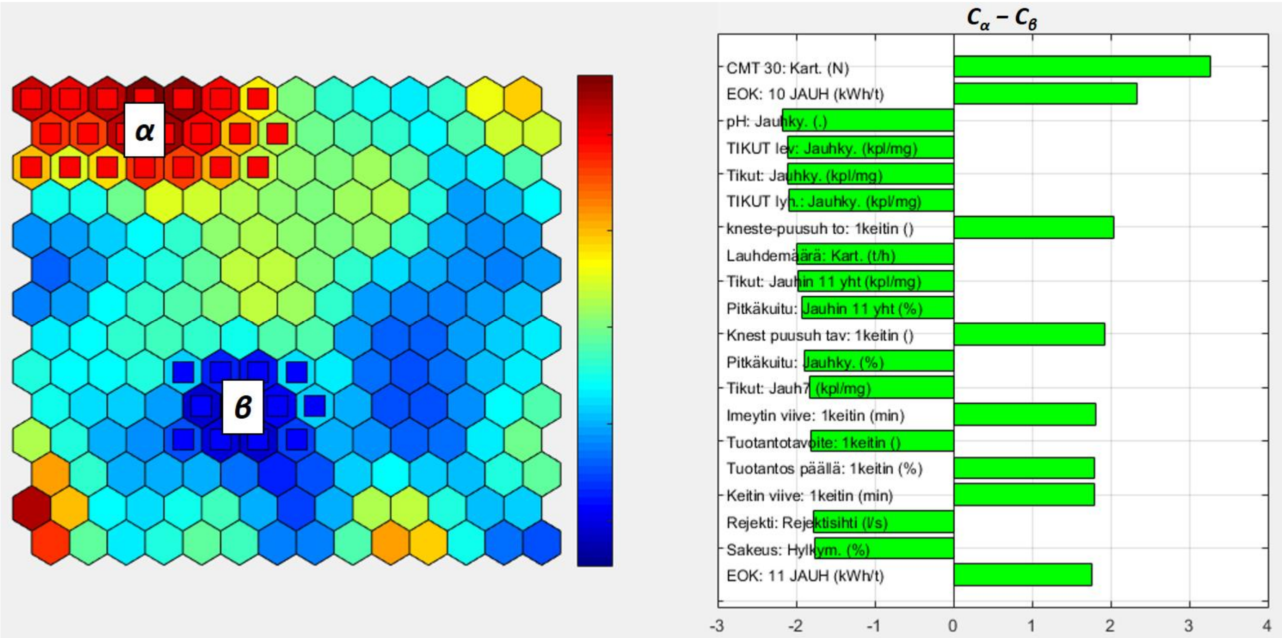


Figure 1. An example of the subtraction analysis in fluting manufacturing. The SOM and the selected areas (α and β) on the component plane of fluting quality (CMT) are shown on the left. The color bar indicates the value of CMT on the map (blue = low, red = high). On the right, the result of the subtraction analysis (C_α - C_β) is shown.

References

[1] Kadlec P., Grbić R., and Gabrys B., Review of adaptation mechanisms for data-driven soft sensors, Computers and Chemical Engineering, 2011, 35, 1-24.

[2] Kohonen T., Self-organizing Maps, 3rd ed., Springer-Verlag, Berlin Heidelberg, New York, 2001.

[3] Heikkinen M., Poutiainen H., Liukkonen M., Heikkinen T., and Hiltunen Y., Subtraction analysis based on self-organizing maps for an industrial wastewater treatment process, Mathematics and Computers in Simulation, 2011, 82, 450-459.

Art Valta*, Mika Ruusunen, Kauko Leiviskä

On-line moisture content estimation of saw dust via machine vision

Keywords: scientific, biorefinery, powder flow, moisture, estimation, cold climate

***Art Valta:** Control Engineering, Environmental and Chemical Engineering, University of Oulu, P.O. Box 4300, 90014 Oulu, Finland, E-mail: art.valta@student.oulu.fi.

Co-Authors: **Mika Ruusunen, Kauko Leiviskä**, Control Engineering, Environmental and Chemical Engineering, University of Oulu, P.O. Box 4300, 90014 Oulu, Finland, E-mail: mika.ruusunen@oulu.fi, kauko.leiviska@oulu.fi

1 Background

One of the research directions currently present seeks to find methods to utilize sawdust in biofuel production. A significant challenge in the use of sawdust is its deviating flowability properties from the more common used raw materials. Furthermore, the biological nature of sawdust brings about significant variations of pertinent physical properties. The flowability of sawdust is affected by granular properties like size and shape but also moisture content. Furthermore, the moisture content is important factor when processing is concerned. Variation in moisture content brings up disturbances during the processing and needs to be controlled to achieve uniform operating conditions. Most of the pre-existing methods of moisture content measuring have too long procedural times with respect to the variation of the moisture content in the feed scales of industrial plant. For this reason, an on-line monitoring method with low capital costs and easy interpretability and generalizability with respect to monitored raw material would be of great use.

It is known that moisture contributes cohesively between objects. When particle size reaches the scales of millimeters or less, the dominant source of liquids' cohesive contribution is due to liquid bridging. Because the cohesion gives rise to deviations in the heap formations it is then logical to ask if these deviations contain some useful information about its source. In this work the angle of repose and the deviations the heap exhibit from it were used as data to infer moisture content in the sample. The aim was to find the computational features, which would manage to explain the moisture levels in adequate manner.

2 Materials & Methods

The effect of moisture content and feasibility of its estimation in granular material was investigated via machine vision. The test scheme consisted of sawdust samples derived from Norway spruce with moisture content adjusted to three distinct levels. The effect of moisture when present as ice or water was compared. The experimental procedure consisted of pouring the sawdust under video camera recording. The equipment setup consisted of a vibrator feeder and custom-built pouring frame. Still images were extracted with fixed sample time from the recording done during the pouring procedure. From the extracted frames the dynamic behavior of cone profile was investigated via statistical means. A schematic illustration of the apparatus is presented in Figure 1. The funnel was fed by sawdust from above via vibrator feeder. The pouring plate was circular so that the poured heap assumes roughly a shape of a circular cone.

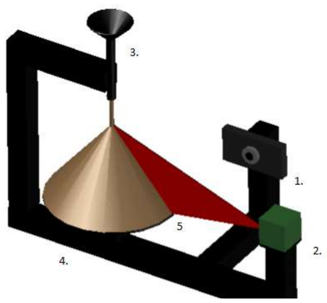


Figure 1. Test environment: 1. Video recorder, 2. Laser source, 3. Funnel, 4. Pouring plate, 5. feature marker.

The still images were extracted from the recorded video material. This corresponded to sampling to time of approx. 0.3 seconds. Any footage which involved arching at the funnel was deleted. After this, to ensure steady state assumption of the material, only last 1813 frames were used for analysis which corresponded to roughly 10 minutes of footage.

ISBN 978-952-5183-56-6

3 Results and Conclusions

Figure 3 shows an example of an extracted image from the footage with the feature marker clearly visible.

Figure 3. Example of an extracted image from the recorded footage.

It was observed during the experimental campaigns that 2nd and 4th standardized moments correlate with moisture content when present as water. When water in the material was present as ice the correlation with 2nd moment was significantly diminished and correlation with 4th disappeared. Corroborated by optical microscopy, this correlation was deduced to be due to liquid bridging in the bulk. Moisture content when present as ice was, however, observed to have a drastic effect on the overall cone shape. Based on these findings, a machine vision application could be feasible way to estimate moisture content on-line in thawed saw dust by using statistical parameters in classification decision making. This would enable cost-effective on-line monitoring of moisture content and a control system to be designed.

Heikki Hyyti*, Juha Mäkelä, Antero Kukko, Harri Kaartinen

An integrated positioning and mapping sensor for forest machinery

Keywords: rotating multi-beam lidar, inertial measurements, sensor fusion, calibration, point cloud, forestry

Extended abstract. Mobile mapping is a promising technology for collect-ing single-tree level inventory data for precision forestry [1, 2, 3]. Forest machinery could be used as a platform for a mobile mapping system. The same instrument could also give forest machinery an ability to perceive forests for automating their operation. For these purposes, a ro-bust and low-cost prototype of a rotating multi-beam li-dar (RMBL) sensor with an integrated inertial measure-ment unit (IMU) is proposed (see Figure 1).

The prototype increases the field of view (FOV) of a Velodyne multi-beam lidar sensor by operating it on a rotating mounting at a configurable fixed inclination. In addition to the Velodyne lidar [4], the prototype is constructed from a motor operated rotating platform, an angular position sensor [5], an inertial measurement unit (IMU) [6], and a computer [7] for real-time processing. The configured FOV of the sensor is 360° × 110°.

As the construction is complex, there are many parameters in the setup which need to be estimated to measure accurate point clouds. The calibration parameters for the prototype sensor are estimated using a data-based calibration procedure which minimizes errors by fitting planes into the lidar point cloud which is collected during a full revolution of the rotating platform. The error minimization is performed for data collected inside a building which has floors and walls that can be assumed planar.

The IMU, on the other hand, is temperature stabilized to a fixed temperature (40°C) and gyroscope and accelerometer biases and gains are estimated for the fixed temperature by a computational parameter estimation method used in [8].

In the paper, we show how to build and calibrate the RMBL sensor and how to calibrate it together with an IMU for future development of omni-directional lidar-inertial odometry. Our calibration method has minimal amount of parameters, the method is simple to use, and it is able to calibrate major part of the parameters in the setup with only a small amount of manual work.

When the sensor is fitted on top of the forest machine cabin (as in Figure 2) it may be used to detect ground level, tree trunks, crowns, and tops (see example data in Figure 3), which are required for many forest inventory pur-poses (see e.g. [1, 2, 3]). The sensor is also able to see the forestry crane constantly which may allow crane and tool positioning in the future [9].

Figure 1: A close up of the integrated positioning and mapping sensor

***Corresponding author: Heikki Hyyti,** Finnish Geospatial Research Institute (FGI), National Land Survey of Finland (NLS) and Department of Electrical Engineering and Automation, Aalto University, E-mail: heikki.hyyti@iki.fi
Juha Mäkelä, Häme Vocational Institute, Häme University of Applied Sciences
Antero Kukko, FGI, NLS and Department of Built Environment, Aalto University
Harri Kaartinen, FGI, NLS and Department of Geography and Geology, University of Turku

Figure 2: A forest machine and the proposed sensor installed on top of the machine cabin at Evo, Häme Vocational Institute. The corresponding author stands next to the cabin.

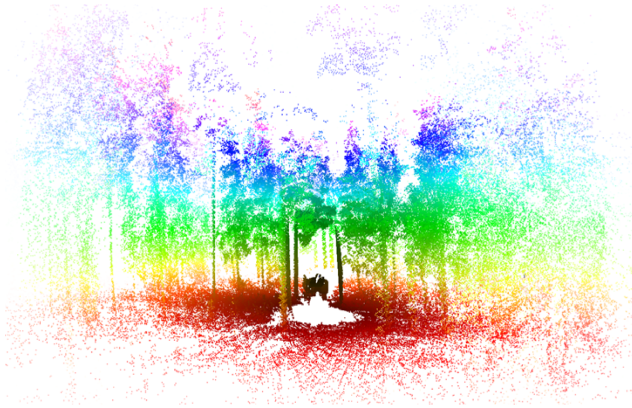


Figure 3: A forest machine inside a forest as viewed by the proposed sensor mounted on top of the cabin. The collected point cloud is colorized by the height as hue and point range as value in a hue-saturation-value (HSV) color space.

Acknowledgments

Strategic Research Council at the Academy of Finland is acknowledged for financial support of project "Competence-Based Growth Through Integrated Disruptive Technologies of 3D Digitalization, Robotics, Geospatial Information and Image Processing/Computing – Point Cloud Ecosystem" (project decision number 293389 / 314312).

References

[1] Hyyppä J, Yu X, Kaartinen H, Kukko A, Jaakkola A, Liang X, Wang Y, Holopainen M, Vastaranta M, Hyyppä H. Forest Inventory Using Laser Scanning. In: *Topographic Laser Ranging and Scanning*, pp. 379–412. Taylor & Francis. 2018;.

[2] Holopainen M, Vastaranta M, Hyyppä J. Outlook for the next generation's precision forestry in Finland. *Forests*. 2014; 5(7):1682–1694.

[3] Vastaranta M, Saarinen N, Kankare V, Holopainen M, Kaartinen H, Hyyppä J, Hyyppä H. Multisource single-tree inventory in the prediction of tree quality variables and logging recoveries. *Remote Sensing*. 2014;6(4):3475–3491.

[4] Velodyne LiDAR. *Puck LITE: Light weight real-time 3D LiDAR sensor*. 2018. Datasheet 63-9286 Rev-H. URL https://velodynelidar.com/docs/datasheet/63-9286_Rev-H_Puck%20LITE_Datasheet_Web.pdf

[5] ASM GmbH. *POSIMAG® - PMIS3/PMIS4: Magnetic Scale Position Sensors*. 2017. Installation and operation manual, MAN-PM-E-17. URL https://www.asm-sensor.com/en/downloads.html?file=files/asmTheme/pdf/pm_man_en.pdf

[6] InvenSense. *MPU-9250 Product Specification Revision 1.1*. 2016. Datasheet PS-MPU-9250A-01 v1.1. URL http://www.invensense.com/wp-content/uploads/2015/02/PS-MPU-9250A-01-v1.1.pdf

[7] Intel. *Intel® NUC Board NUC7i5BNB and Intel® NUC Board NUC7i7BNB*. 2018. Tech. prod. spec., J59951-008. URL https://www.intel.com/content/dam/support/us/en/documents/boardsandkits/NUC7i5BN_NUC7i7BN_TechProdSpec.pdf

[8] Hyyti H, Visala A. A DCM based attitude estimation algorithm for low-cost MEMS IMUs. *International Journal of Navigation and Observation*. 2015;2015:18.

[9] Lindroos O, Ringdahl O, La Hera P, Hohnloser P, Hellström TH. Estimating the position of the harvester head–a key step towards the precision forestry of the future? *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering*. 2015;36(2):147–164.

Henna Tiensuu*, Satu Tamminen, Olli Haapala, Juha Röning

Intelligent methods for root cause analysis behind the center line deviation of the steel strip

Extended abstract: This article presents a statistical prediction model-based intelligent decision support tool for center line deviation monitoring. Data mining methods enable the data driven manufacturing. They also help to understand the manufacturing process and to test different hypotheses. In this study, the original assumption was that the shape of the strip during the hot rolling has a strong effect on the behaviour of the steel strip in Rolling, Annealing and Pickling line (RAP). Our goal is to provide information that enables to react well in advance to strips with challenging shape. In this article, we show that the most critical shape errors arising in hot rolling process will be transferred to critical errors in RAP-line process as well. In addition, our results reveal that the most critical feature characterizes the deviation better than the currently used criterion for rework.

In Tornio, the stainless steel is cold rolled with an integrated rolling, annealing and pickling line, which is called a RAP-line. The center line deviation of the steel strip in the RAP-line is a major quality factor that can produce serious problems if the strip did not stay in place during RAP processing. In the worst case, a diverged strip position can stop the whole production and brake the devices. Hot rolling strip center line deviation at the previous process step is a commonly used and easily available measurement of the strip shape. It could be possible to simulate the behaviour of the strip with a certain shape in the RAP-line during different individual phases. Ilmola et al present a very exact picture of the rolling process of the steel strip in two parts, the hot rolling and heat transfer and microstructure formation during water-cooling [1]. However, in this case, the incoming strips at the RAP-line include a large amount of different shapes, and to get the big picture of the whole production, all of them require simulating. In addition, there are hundreds of products behaving differently because of their chemical composition or the mechanical properties, and thus that the simulation work would be huge if not practically impossible. With data mining methods, the big picture of the process can be achieved quickly. These methods can process a large set of different process settings and products data simultaneously and take into account the variation caused by the measurement error or actual realization related to the features of the products and the process parameters [2], [3], [4]. Powerful machine learning methods are capable of modeling highly nonlinear process parameter dependencies and enable the effective use of the process data.

In this application, the center line deviation is predicted using gradient boosting methods (GBM) [5]. The idea of this machine learning algorithm is to form a strong learner by combining together the set of iteratively estimated weak learners. The model is able to treat efficiently the complex and nonlinear relationships within the data set, which is mandatory with industrial applications. Other advantages are that the method is capable of processing observations with missing information, and contrary to neural networks, it works also with smaller data sets. Due to the complexity of the center line deviation assessment, a lot of attention has been paid to the selection of the response variable that describes the position deviation best. We ended up considering the 90 m of the inner circle of the strip coil and calculated the mean of the process variable, ST6 super position for describing the center line position of the strip. Next, we applied an average filtering (n=10) for ST6 super position values of the selected length and calculated the difference between the mean of the ST6

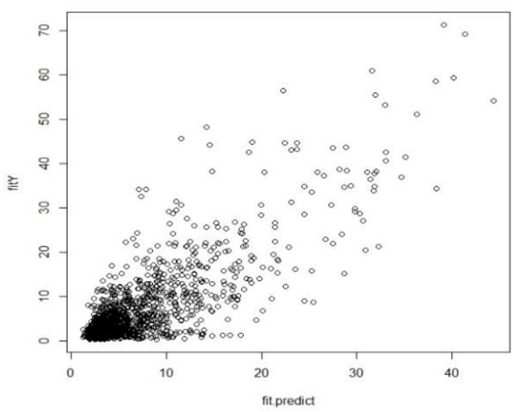


Figure 1. Predicted ST6 super position (x-axis) vs. measured values (y-axis) in the test set. A product group with inferior performance is highlighted (black).

ISBN 978-952-5183-56-6

super position and the filtered curve. The formed response variable was predicted with GBM-model that was implemented with R-program. The overall correlation between the measured and predicted values of the test set was 0.74, the root mean square error was 7.2 and the mean absolute error was 4.6. The scatterplot between the predicted response variable and the measured values in the test set is shown in Figure 1.

The modeling results indicate that the currently used criterion for rework is not the best candidate to characterize the strip behavior. Instead, the most important parameter is the slope_max, which describes the asymmetrical shape of the strip during hot rolling. From Partial dependence plot (PDP) in Figure 2, it can be clearly seen that the higher the slope_max is during hot rolling, the higher the center line deviation is in RAP process correspondingly. The increase in deviation is especially large after 40 units. This result proved the hypothesis that the shape errors in hot rolling forecast problems also in RAP-line. The thickness of the strip has an impact on the response variable as well. Our results reveal also the less critical shape errors, which are the wedge shape and the longitudinal deviation measured from the middle of the strip.

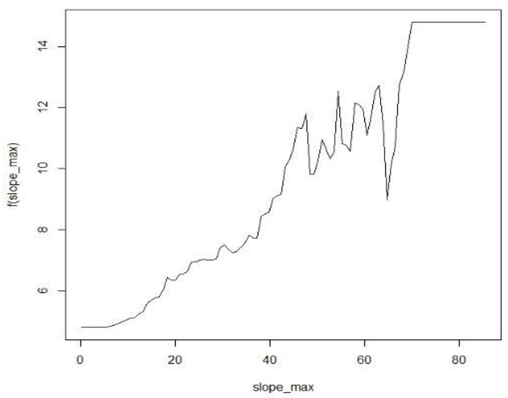


Figure 2. The PDP for slope_max reveals the feature's increasing impact on the response. Especially, after 40 units, the feature has a hazardous effect on the center line position.

It is important to reveal the reasons behind the predictions, especially, when a product has a higher predicted risk for the failure. In this application, SHapley Additive exPlanation (SHAP) values for each product were calculated based on the product group [6]. Thus, the products were compared to the average performance within the group of similar products. We selected one example to demonstrate the usage of the method. The product with bad prediction is shown in Figure 3. As can be seen, the prediction for center line deviation is 31.24 with the bad one, when the average prediction is 11.54 for this steel type in general. The phi value describes the strength of the feature value contribution in the prediction. The strongest candidate behind a poor prediction is slope_max. Also, the membership in the thinner strips class increases the risk.

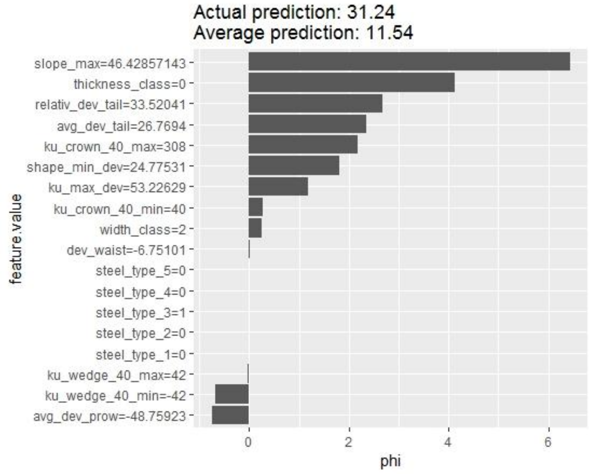


Figure 3. SHAP values for a bad product with a prediction of 31.24, while the average prediction is 11.54 inside the same steel group.

As a result of this research, we found the best response variable that describes the center line deviation. Our root cause analysis behind the center line deviation gives essential knowledge to the process development workers at the Tornio mill. We were able to define a clear critical limit value 40 for slope_max. In the first step, this information can be used for redirecting the strips which exceed the limit to repair treatment before RAP-line. It is also possible to implement the model for online use and to predict more efficiently the products that need to be repaired. The individual information behind the prediction for each product provides useful guidance for the rework.

The developed model enables the user to understand better the quality of the products, how the process works, and how the quality model predicts and performs. The results can be developed further to a smart decision support tool that helps to find out the best way of dealing with the critical products. The tool enables the identification of the quality problems of the steel strips at the earliest possible moment, which leads to the reduction of the rejection risk and to increased profits for the producer. Because of the laborious and manual data collection, the current model covers the main product groups. The performance of the model can be improved by collecting more data from the product groups with a smaller number of representatives, but online learning methods could provide a more serviceable solution in the long run.

Keywords: smart decision support, data driven manufacturing, artificial intelligence, data mining, steel strip rolling, GBM

*Henna Tiensuu: University of Oulu / BISG, E-mail: henna.tiensuu@oulu.fi

Satu Tamminen: University of Oulu / BISG, E-mail: satu.tamminen@oulu.fi

Olli Haapala: Outokumpu Stainless Oy, Tornio, E-mail: Olli.Haapala@outokumpu.com

Juha Röning: University of Oulu / BISG, E-mail: juha.roning@oulu.fi

References

[1] Ilmola J., Pohjonen A., Seppälä O., Leinonen O., Larkiola J., Jokisaari J., Putaansuu E., Lehtikangas P., Coupled multiscale and multiphysical analysis of hot steel strip mill and microstructure formation during water cooling. Procedia Manufacturing 15, proceedings of the 17th International Conference on Metal Forming, METAL FORMING 2018, Toyohashi, Japan, 2018, 65-71

[2] Tamminen S., Juutilainen I., Röning J., Exceedance probability estimation for a quality test consisting of multiple measurements. Expert Syst. Appl. 40(11):4577–4584, 2013

[3] Juutilainen I., Modelling of Conditional Variance and Uncertainty Using Industrial Process Data. Acta Universitatis Ouluensis: Technica, University of Oulu, 2006

[4] Engel J., Modelling variation in industrial experiments. Applied Statistics 41:579–593, 1992

[5] Friedman J. H., Stochastic gradient boosting. Comput. Stat. Data Anal. 38(4):367–378, 2002

[6] Lundberg S. M., Lee S. I., A Unified Approach to Interpreting Model Predictions. In: Advances in Neural Information Processing Systems 30, edited by Guyon I, Luxburg UV, Bengio S, Wallach H, Fergus R, Vishwanathan S, Garnett R, pp. 4765–4774. Curran Associates, Inc. 2017

Iiris Joensuu*, **Marjatta Piironen**

Smart diagnostics for continuous process improvements and optimization in forest industry

Keywords: Diagnostics, data analysis, pulp and paper industry

***Iiris Joensuu:** Kemira Oyj, Espoo R&D Center, Finland, iiris.joensuu@kemira.com

Marjatta Piironen: Kemira Oyj, Espoo R&D Center, Finland, marjatta.piironen@kemira.com

1 Background

Today forest industry has a pressure to improve process performance and cost efficiency in a very competitive market. Process improvements are also required to reach tightening environmental regulations. At the same time, digitalization of processes generates more and more data 24/7 to be utilized in these challenging circumstances. Smart diagnostic tools have been developed for turning the massive amount of data into more understandable information. This information can be used for continuous chemistry and process improvements in pulp and paper industry.

2 Method

Smart diagnostic tools are available in a web-based platform. The platform contains versatile methods for data collection, data pretreatment, data analysis, feature extractions, visualization and results reporting. The platform enables remote and real time diagnostics by automated operations. Users can drill into a large data set to find the best explaining variables for a problem or diagnostic target.

Typical diagnostic study can be problem solving, chemical performance analysis or benchmarking of chemistries. Smart diagnostics is a combination of strong knowhow of chemical phenomena, application knowledge, chemistry specific data and advanced analysis methods.

Diagnostics is an iterative process starting with target definition, feature extractions and analysis (Figure 1). Observed findings, learnings and improvements proposal are reported and shared with process experts.

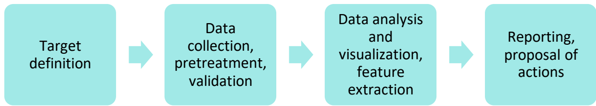


Figure 1. Diagnostic process.

3 Results

A typical work flow in a customer case is presented as a troubleshooting example in a paper machine. Target was to find reasons for the high number of paper defects (Figure 2). Diagnostic work started with data collection and pretreatment. Process data was merged with chemistry specific online measurements. Root causes for issues were analyzed by versatile statistical methods (e.g. t-test, best explaining set). Two data sets, a reference and a defect issues period, were compared by t-test (Figure 3). The best explaining set is based on a stepwise regression model. It defines the variable set which best explains the target variable (Figure 4).

Figure 2. Paper defects.

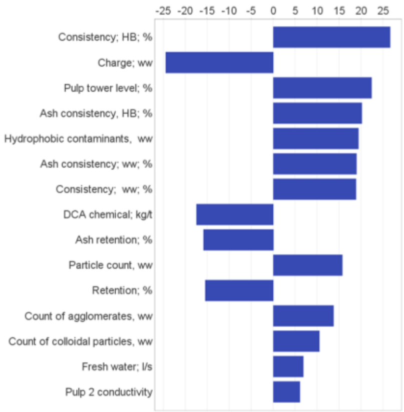


Figure 3. Diagnostic results (t-test).

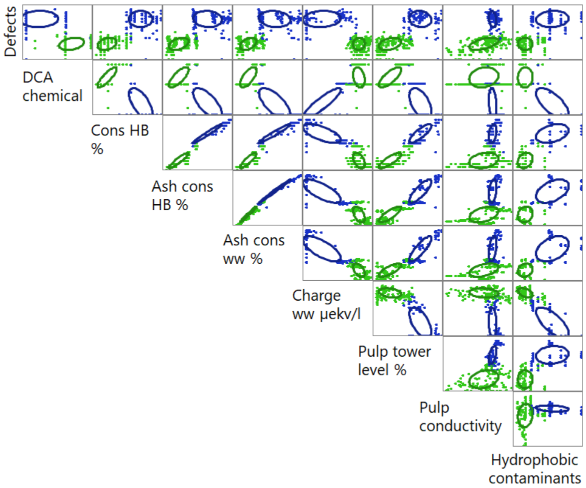


Figure 4. Diagnostic results.

Data analysis results indicate that there were two root causes for paper defects: The total and ash consistencies of the pulp suspension in the headbox were high and the quality of pulp was clearly weaker. Weak pulp quality was seen as the higher amount of dissolved anionic compounds (charge) and hydrophobic contaminants (wood pitch). Higher charge weakened the performance of cationic chemistry. Therefore, retention was lower. Weaker retention together with the high amount of colloidal wood pitch and high ash content caused the deposition of detrimental contaminants and further the higher number of paper defects.

Findings were reported, and several chemistry improvements were proposed to the customer. The efficient and optimized control of detrimental contaminants is a key factor for preventing product quality issues and loss of production. The paper mill could improve the process performance and reduce almost 20-40 % of paper defects by optimized chemistry.

4 Conclusions

Diagnostic studies have created proven value in hundreds of customer cases in pulp and paper industry. Smart diagnostics enables continuous performance and cost optimization, high quality chemical applications and proactive customer care. Solutions can be easily reused in new processes. The platform supports the creation of new customer services.

Extended Abstracts
ISBN 978-952-5183-56-6

Marjatta Piironen*, **Iiris Joensuu**

Smart monitoring system for the management of hydrophobic contaminants in pulp and paper processes

Keywords: Chemistry monitoring, chemistry control, pulp and paper industry

***Marjatta Piironen:** Kemira Oyj, Espoo R&D Center, Finland, marjatta.piironen@kemira.com

Iiris Joensuu: Kemira Oyj, Espoo R&D Center, Finland, iiris.joensuu@kemira.com

1 Background

Hydrophobicity of particles is a very important parameter in many industrial processes. In papermaking, hydrophobicity is closely related to the presence of wood pitch, white pitch or stickies. These hydrophobic contaminants may be as free particles or attached to other particle surfaces or agglomerated larger particles (Figure 1, [1]). Hydrophobicity is known to cause depositions and runnability problems in the paper machine. The measurement of hydrophobic contaminants is typically based on time-consuming laboratory analysis.

A new online technology has been developed for the smart, rapid and easy measurement of hydrophobic particles.

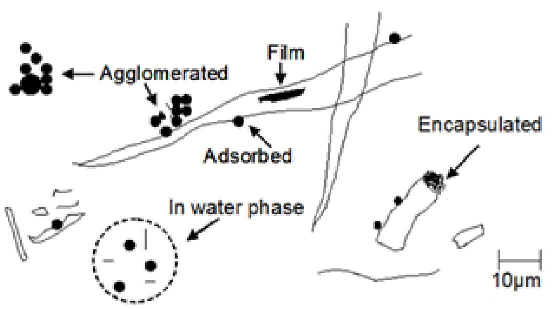


Figure 1. Example of wood pitch in wet end [1].

2 Method

Online system is fully automated. It takes samples from filtrates and pulp streams (max 1% consistency) and adds hydrophobic stain to the sample. Then the system automatically divides particles into different populations and measures particle counts and hydrophobicity by populations like colloids, fines and agglomerates. Sample filtration is not needed before measurement. Therefore, online system gives also information from bigger particles like fibers and big agglomerates. This is very important for improving chemical treatment. The total effect of chemicals can be seen on all particle types.

Comprehensive comparison analysis has shown that online method gives similar type of information as the laboratory reference method, Flow cytometer. Figure 2 shows a comparison example for wire water samples. Online hydrophobicity correlates to the corresponding laboratory results.

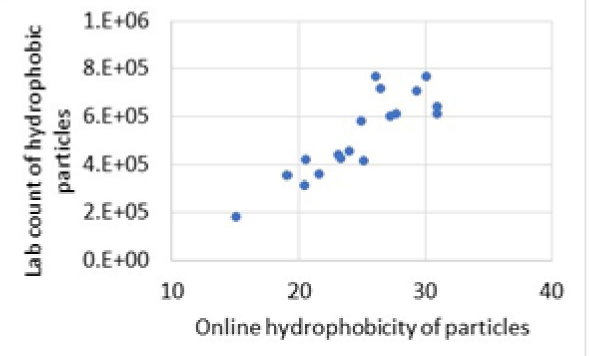


Figure 2. Hydrophobic particles in wire water samples: Online versus Laboratory method.

3 Results

The online system is used for the monitoring of hydrophobic contaminants (wood pitch) in the white-water streams of a marketing pulp machine and a lightweight coated (LWC) paper machine.

Different pulp types can be clearly seen in hydrophobicity. Kraft Aspen contains the highest amount of wood pitch (Figure 3). This data has been utilized for improving the washing of pulps with chemicals.

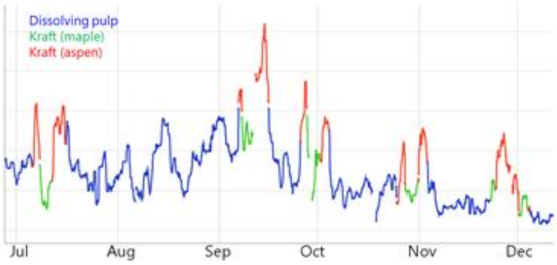


Figure 3. Hydrophobicity of various pulp types.

Pitch defects in the LWC machine increase when colloids exceed a threshold value (Figure 4). Depositions have been minimized for optimizing chemical doses to pulp streams.

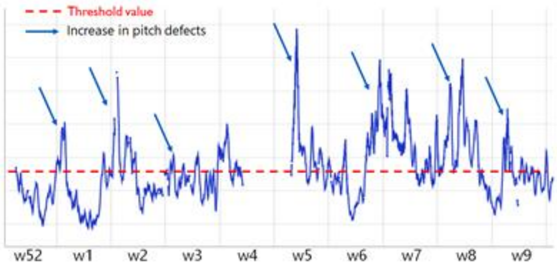


Figure 4. Count of colloids versus pitch defects.

4 Conclusions

Smart management of hydrophobic contaminants includes the use of online hydrophobicity data, chemistry application knowhow, chemistry control and optimization. Monitoring systems have been applied widely for different chemical applications in pulp and paper processes. Several systems are globally running in the mills.

Online hydrophobicity data gives more complete understanding of what is happening in real time within the process. Results have shown that this technology is an excellent tool for monitoring, troubleshooting and optimizing wet end chemistry and improving chemical performance.

References

[1] Back E.L., (2000) Resin in Suspension and Mechanism of It’s Deposition. Pitch Control, Wood Resin and Deresination. Tappi Press, Atlanta GA 2000, pp 151-184

Jukka Kortela*, Sirkka-Liisa Jämsä-Jounela, Pekka Tonteri, Arto Ahonen

Factory of the Future Automation Set Up for Process industries

Abstract: Today's graduate of university of technology must be a designer with multidisciplinary background; he has to understand the basics in chemical engineering, modelling and simulation, process control and automation, hybrid systems in processes to be able to effectively connect and configure unit processes, production lines and the whole plant. Implementation of Big Data, IoT and Cloud computing methodologies in research is an essential part of multidisciplinary learning, especially in higher education. There is a need for a modern factory of future automation set up which gives an opportunity to perform high quality multidisciplinary research and education across the schools borders and to serve our global process industries' needs. There is a need for open data valley to co-operate with our customers in industries and colleagues in international research centers. Currently, there is no ready open cloud environment especially designed for process industries. Therefore, the aim is to further develop our Factory future process automation set up, and enable the open connectivity, data analysis, and algorithms development in Siemens MindSphere and Microsoft Azure environments.

Keywords: IoT, cloud computing, OPC UA, advanced control, data analytics, Azure, MindSphere

***Corresponding Author: Jukka Kortela:** Aalto University, School of Chemical Engineering, P.O. Box 16100, FI-00076 Aalto University, Finland, E-mail: jukka.kortela@aalto.fi

Co-authors:

Sirkka-Liisa Jämsä-Jounela: School of Chemical Engineering, P.O. Box 16100, FI-00076 Aalto University, Finland E-mail: sirkka-liisa.jamsa-jounela@aalto.fi

Pekka Tonteri: IT Solution Development, P.O. Box 11000, FI-00076 Aalto University, Finland, E-mail: pekka.tonteri@aalto.fi

Arto Ahonen: IT Solution Development, P.O.Box 11000, FI-00076 Aalto University, Finland, E-mail: arto.ahonen@aalto.fi

1 Status of the Factory of Future Automation Set Up in Abio Today

The factory of future automation setup consists of ABB System 800xA DCS with the duplicated main servers, as shown in Figure 1. Configuration stations and operator stations are virtualized Windows workstations. They are installed in two highly efficient physical Dell 730xd servers that can be accessed remotely for the training and learning purposes. The sensors / actuators can be accessed through the real-time Ethernet and PLCs (Programmable Logic Controller), or Rasberry Pi I/O Gateway by utilizing the 5G cellular testbed network to provide the redundant wireless access with low latency for the installed equipment.

2 Control and IO modules

Control and I/O module of ABB System 800xA consists of standards-based hardware and software with industrial I/O interfaces. Information management module of ABB System 800xA collects, stores, and presents the real-time process, historical and business data. The OPC UA Server provides OPC UA client with access to the System 800xA. From the OPC UA servers address space the OPC UA clients can read measurements and manipulate parameters.

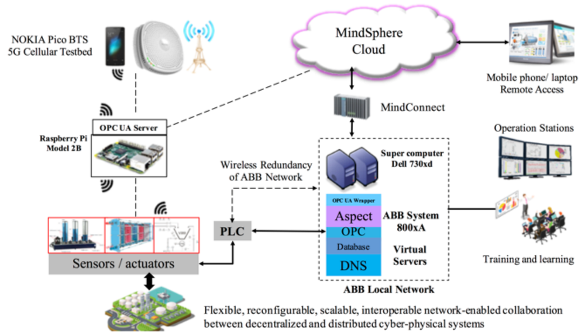


Figure 1. Overall Architecture of the Factory of Future Automation Set up

ISBN 978-952-5183-56-6

3 Further Development of the Future Process Automation Set Up

3.1 Open Connectivity

In the setup, the data is collected from OPC UA data sources via MindConnect Nano gateway into MindSphere cloud computing system where the data can be visualized and analytics algorithms can be executed for the data, as illustrated in Figure 2. The OPC UA connection has been implemented with MindConnect Nano to make possible the automation set up and companies to connect into the MindSphere cloud. MindConnect Nano is a hardware device that establishes the connection to MindSphere in order to collect data from an equipment and transfer it to MindSphere.

MindConnect Library provides a software development kit (SDK) which enables self-programming of the customer or the use case specific connectivity agents. It supports encrypted transmission of on-site data to MindSphere through a secure internet connection, to enable cloud-based applications and services.

3.2 Development of the FDD and machine learning algorithms

The Azure and Cloud Foundry are platforms as a service (PaaS), providing a development and deployment environment together with MindSphere. The MindSphere Cloud Platform provides a variety of supporting services to make application development easier. Through the APIs different processes can be automated, i.e. manage users and assets, retrieve and store Industrial IoT data. In addition, the third-party algorithms, such as scikit-learn, and applications can be included into the set up. The proposed advanced teaching and process monitoring system is currently being evaluated with test-algorithms implemented in the Azure and Cloud Foundry cloud.

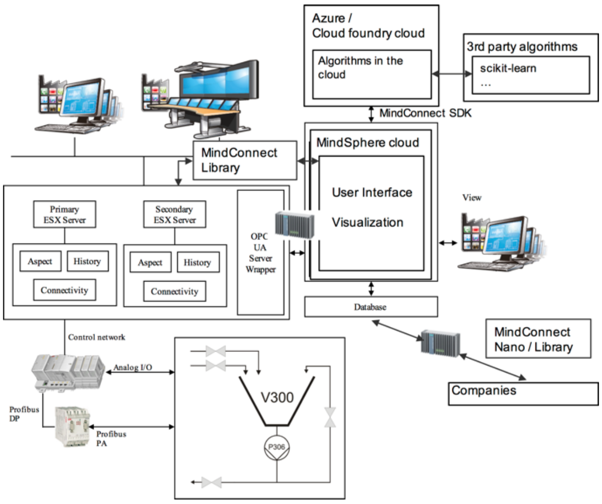


Figure 2. Cloud platform of the Factory of Future Automation Set up

4 Future research

The future research of the set up includes the evaluation of the proposed advanced teaching and process monitoring system and the implementation of the custom developed algorithms in the Azure and Cloud Foundry cloud.

Jari Ruuska[1]*, Riku-Pekka Nikula[1], Eemeli Ruhanen[2], Janne Kauppi[3], Sakari Kauvosaari[3], Mika Kosonen[3]
[1]University of Oulu, Control Engineering
[2]Yara Suomi Oy, Siilinjärvi Mill
[3]Outotec (Finland) Oy

Data-analysis of paste thickener

Keywords: paste thickener, data-analysis, linear regression

***Corresponding Author:** E-mail: Jari.Ruuska@oulu.fi

Modern world is very dependent on materials. Saying: "What you can't grow, you need to dig" is true and it means that people need different kind of materials to produce tools and necessities for their day-to-day use. Due to this fact, mining is becoming more and more important branch of industry. A lot of attention is paid to make it as efficient as possible. As the tons of rock crushed increases, also the amount of waste rock increases. For example, the tailings from the flotation circuit contain a lot of water and it is good to lower water content before storing into tailings pond. A paste thickener can be used to lower water content. The behavior and effecting variables of vessel will be investigated to make operation cost-efficient. Thickening is most economical method within several dewatering techniques. The thickening process normally occurs in large-diameter tanks where solids particles settle under the influence of gravity, i.e. sedimentation. Jewell *et al.* [1] raise a valid challenge into discussion: operation of paste thickeners has different practical problems. One of them is a narrow operating window as a small change in the underflow solids concentration may have a major impact on the properties (for example pumpability and flowability) of the underflow. Due to these issues, the control of paste thickener can be challenging.

The solids content of slurry is typically increased in thickeners. Clean overflow and maximum solids concentration in the underflow are the general objectives. Flocculants rate and underflow rate are the two independent variables, which are typically used for control. The dependent variables are for example rake torque, underflow density, overflow turbidity, solids interface level (bed depth), solids inventory (bed pressure), solid settling rate and underflow viscosity.

The research problem in question is that the out coming paste is sometimes difficult to pump. The phenomena leading to this situation is not well known. In the worst case scenario this phenomena causes clogging in the piping. A data analysis is done to find variables affecting and correlating with the pumping problem. The scope is in the measurements from feed line, thickener and underflow. The goal is to have better understanding on phenomena after this phase. The data-analysis is done using paste line pressure difference as a response variable and dividing the data collected from Yara's Siilinjärvi mill in two parts; high and low pressure difference operation areas. Analysis is focused on thickener 1. The knowledge of found variables having effect on pressure difference then can be utilized in further development.

The data set used for data-analysis contains data from Yara's both paste thickeners, but after discussing with plant experts the data-analysis was limited only to thickener one. Whole data set contained all together 73 measurements from February -17 to February -18. The frequency of measurements was one minute. In actual data-analysis, twenty-six variables from the thickener feed, thickener and paste line were used. Information about performance optimization of paste thickening can be found for example from [2].

The process was analyzed by dividing data first into high and low pressure difference operation areas and then clustering the data from variable Paste line 1 and response variable. As a summary it can be said that clustering has a major effect on correlation.

As drawing scatter diagrams, it was noted that in the process there is at least two operation areas. The paste line pressure difference can be estimated using linear regression models promisingly; especially during booster pump KA7402 usage.

ISBN 978-952-5183-56-6

References

[1] Jewell, R.J., Fourie, A.B., Lord, E.R., 2002. Paste and Thickened Tailings: A Guide. Australian Centre for Geomechanics, University of Western Australia.

[2] Ruhanen E., Kosonen M., Kauvosaari S., Meintjes C., Performance optimization of paste thickening at the Yara Siilinjärvi Plant. In R.J. Jewell and A.B. Fourie (Eds.), Paste 2018 - Proceedings of the 21st international seminar on paste and thickened tailings, Perth, Australia: Australian Centre for Geomechanics, 75-88

S. Kauvosaari*, J. Kaartinen, M. Torvinen

Performance optimization of copper flotation at the Boliden Kylylahti plant

***Corresponding author:**
Sakari Kauvosaari, Outotec (Finland) Oy, Tasavallankatu 22, FI-70620 Kuopio, Finland, E-mail: sakari.kauvosaari@outotec.com

Other authors:
Jani Kaartinen, Outotec (Finland) Oy, Tasavallankatu 22, FI-70620 Kuopio, Finland, E-mail: jani.kaartinen@outotec.com
Markus Torvinen, Boliden Kylylahti Oy, Juuantie 111, FI-73670 Luikonlahti, Finland, E-mail: markus.torvinen@boliden.com

Keywords: flotation, grade, recovery, process control, optimization, APC, MPC

BACKGROUND

The Boliden Kylylahti plant is located in the eastern part of Finland, about 50 km east from Kuopio. The operation includes the Kylylahti underground mine in Polvijärvi and the Luikonlahti processing plant at Kaavi, 43 km from the mining area. The Kylylahti plant produces over 50 000 tons/a of copper concentrate. Other main products are zinc and gold. Copper, zinc and gold concentrates produced at Luikonlahti are delivered to Boliden's own smelters in Harjavalta and Kokkola. The concentrator plant was originally established by Myllykoski Oy in 1968 and it was operational until 1983. After a silent period of nearly two decades, Kylylahti mine was re-opened by Altona Mining Ltd. in 2012 and acquired by Boliden in 2014. Based on the latest ore reserve estimates, the mine is expected to operate until 2020.

ABOUT THE PROCESS

Fresh ore is transported with trucks to the concentrator plant, where it is first crushed and then fed to typical 3-stage grinding circuit with a targeted particle size around 100 μm. A special feature in Kylylahti's grinding circuit is that it includes a Knelson concentrator for trapping the liberated gold particles at an early stage of the process. The gold missed by the Knelson concentrator will be recovered later on, together with copper, and separated in smelting.

After the grinding, first stage of the actual separation process is copper flotation circuit. It contains four 16 m^3 roughers cells and two 16 m^3 scavenger cells. The cleaner stage is organized in three phases by twenty-two cells (2 x 30 m^3, 2 x 20 m^3, and 18 x 3 m^3). The following two flotation stages are zinc and pyrite circuits, respectively. The Advanced Process Control (APC) presented here was implemented to copper circuit because 90% of turnover comes from copper and gold. Also, the copper flotation is the first circuit of flotation process and thus stabilization and optimization of the copper stage will benefit later processing stages as well.

APC SOLUTION

APC control is implemented by using Outotec's Advanced Control Tools® (ACT) platform. ACT platform is dedicated environment for advanced process control solutions. In general, ACT platform includes (see Figure 1) engineering tools, control engine, historian database, data interface to external systems and operator interface. Typically, first four items are executed in dedicated ACT server computer and operator interface in separated ACT client computer.

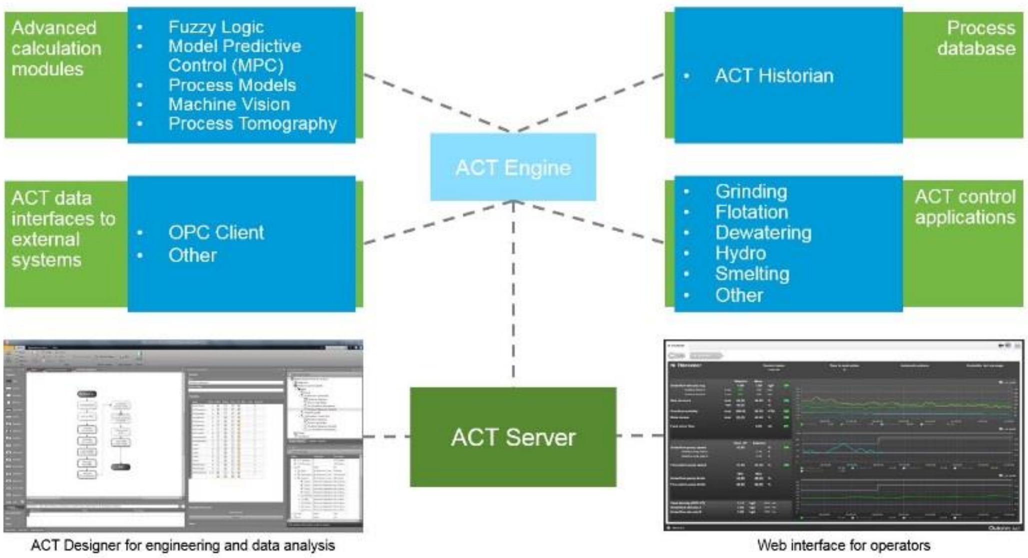


Figure 1. Outotec's Advanced Control Tools platform structure.

ISBN 978-952-5183-56-6

There were several reasons justifying the implementation effort of higher level control, namely, 1) big variations in the feed copper content, 2) low copper recovery, and 3) different control principles between shifts. The selected APC control method for Kylylahti was Model Predictive Control (MPC) and it was implemented during spring and summer 2017.

The existing process instrumentation had been recently upgraded with Outotec's FrothSense cameras (located in Cu-rougher and Cu-scavenger banks) and froth speed controls (froth speed is controlled by manipulating air feed rate and slurry level of cells equipped with FrothSense cameras). Additionally, X-Ray fluorescence based Courier 5™ analyzer provides the most important process measurements (elemental grades) for APC control.

For the MPC solution, the most important control variable is copper tailings Cu content, which correlates strongly with overall Cu-recovery. The other control variable is rougher concentrate Cu%. This has correlation with final concentrate Cu%.

APC control manipulates set points for froth speeds and reagent dosing for fulfilling the desired performance. Additionally, when the performance is on a good level, the controller minimizes reagent usage to cut costs.

RESULTS

The performance of APC control was tested by comparing copper grade and recovery results with a given feed grade (average over the test period). The control was enabled and disabled in 24-hour cycles to eliminate the effect of feed changes and, on the other hand, to obtain statistically credible results. The Figure 2 shows the feed grade changes during the test period. Feed grade, concentrate grade and recovery were based on on-line Courier analyzer values.

Figure 2. Copper feed grade (%) during the test period (15 days of data, spring 2018)

Both values, grade and recovery, are slightly higher when APC control was enabled. Figure 3 shows the online analyzer measurements during ON/OFF tests. However, more important is the stabilizing effect shown in Table 1: the standard deviations of grade and recovery were decreased significantly.

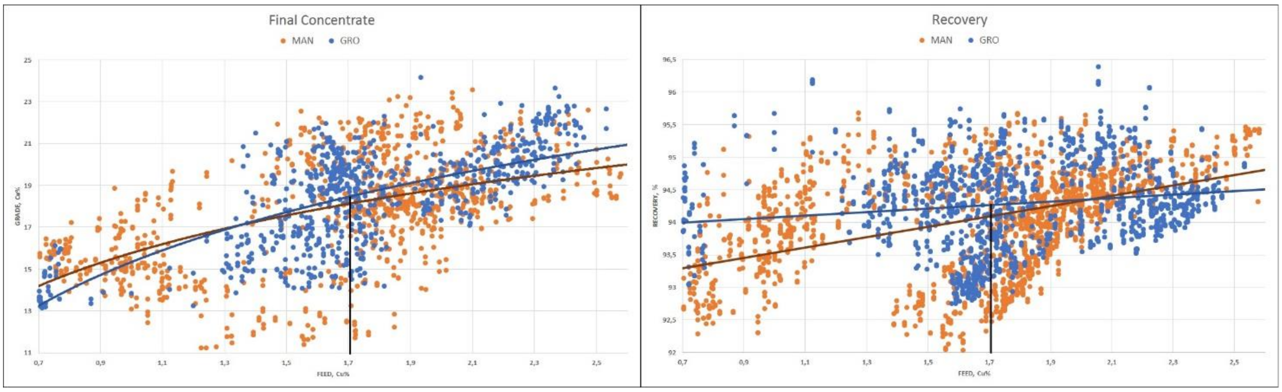


Figure 3. Grade and recovery changes during ON/OFF tests.

Table 1. Grade and recovery changes during ON/OFF tests.

	ACT control	Concentrate Cu grade (%)	Cu recovery (%)
Value at averaged feed (1,7%)	ON	18,46	94,27
	OFF	18,12	94,09
standard deviation	ON	1,59 **(-40%)**	0,67 **(-15%)**
	OFF	2,63	0,79

M. Kosonen*, E. Ruhanen, S. Kauvosaari, C. Meintjes

Performance optimization of paste thickening at the Yara Siilinjärvi plant

*Corresponding author:
Mika Kosonen, Outotec (Finland) Oy, Tukkikatu 1, P.O. Box 29, FI-53101 Lappeenranta, Finland, E-mail: mika.kosonen@outotec.com

Other authors:
Eemeli Ruhanen, Yara Suomi Oy, Siilinjärvi Mine, Nilsiäntie 501, P.O. Box 20, FI-71801 Siilinjärvi, Finland, E-mail: eemeli.ruhanen@yara.com
Sakari Kauvosaari, Outotec (Finland) Oy, Tasavallankatu 22, FI-70620 Kuopio, Finland, E-mail: sakari.kauvosaari@outotec.com
Chris Meintjes, Outotec Pty Ltd, 40 kings Park Road, West Perth WA 6005 Australia, E-mail: chris.meintjes@outotec.com

This abstract and related presentation is a shortened reproduction of the results presented at Paste 2018 Conference in Perth, Australia, 11-13 April 2018[1]. Main focus is on the results obtained by applying a multivariable, optimizing control strategy to two new paste thickeners manufactured and commissioned by Outotec for Yara Siilinjärvi plant.

The Yara Siilinjärvi plant is located in the central part of Finland, some 25 km north from Kuopio. The site consists of a mine, two sulphuric acid plants, one phosphoric acid plant, one nitric acid plant and one NPK-fertilizer plant. The Siilinjärvi mine produces about one million tons of apatite concentrate, which creates approximately 10 million tons of tailings per year.

At the beginning of 2017, tailings handling in Yara Siilinjärvi was brought to a new era, when the conventional tailings storage facility was replaced with a new tailings treatment plant. The aim was to extend the lifespan of the 1 150-hectare tailings storage area without increasing the footprint, since this would have meant new land purchases, dam increases and related permitting processes. The solution was to construct a completely new tailings treatment plant, where the water content of the tailings material is reduced so much that the resulting paste can be stacked in piles and thus the same amount of material requires much smaller physical footprint. The new plant, located 6.6 km's from the concentrator, was commissioned by Outotec and – thanks to the advanced process control solution presented here – is currently being run in un-manned mode remotely from the main plant's control room. The new high-density tailings disposal system with two deep cone-type paste thickeners increased the percentage of solids in the slurry from 45–48% to 66–69%, making it possible to deposit as paste. This extended the lifetime of the current tailings storage facility by 15 years – from 2020 until 2035.

The rheology of the tailings in Siilinjärvi is unique, due to the minerology of the slurry. In particular, the high content of coarse mica makes thickener operation challenging and makes high density pumping sensitive to disturbances. Therefore, the importance of process control cannot be underestimated. Advanced control system is needed to maintain process stability and the desired operation point in varying situations, and to enable remote operation as mentioned earlier. The presented solution is based on Outotec's Advanced Control Tools (ACT) platform, which can be cost-effectively utilized with any customer DCS/PLC system (Distributed Control System/Programmable Logic Controller). With the ready-made application package, implementation is straightforward, and only a minimal amount of system specific tailoring is needed. The ACT system in Yara is highly integrated with the plant DCS, so that the operators have full access to user interface, alarms, interlockings, history data and documentation, through the DCS displays.

The control is based on Model Predictive Control (MPC), which is nowadays included in Outotec's ACT platform. The overall control system structure is shown in Figure 1 below. Controlled variables are: Underflow density (kg/m3), Overflow solids content (%), Bed mass (%), Bed level (m) and Rake torque (%). From these variables, underflow density was selected to be a primary control variable, which has a precise target value and the highest priority during normal operation. This was a natural choice, because the main target of the whole paste plant is to produce stable and high enough underflow solids content, thereby ensuring stable pumping and good tailings beaching properties.

[1] Ruhanen, E, Kosonen, M, Kauvosaari , S & Henriksson, B 2018, 'Optimisation of paste thickening at the Yara Siilinjärvi plant', in RJ Jewell & AB Fourie (eds), Proceedings of the 21st International Seminar on Paste and Thickened Tailings, Australian Centre for Geomechanics, Perth, pp. 75-88.

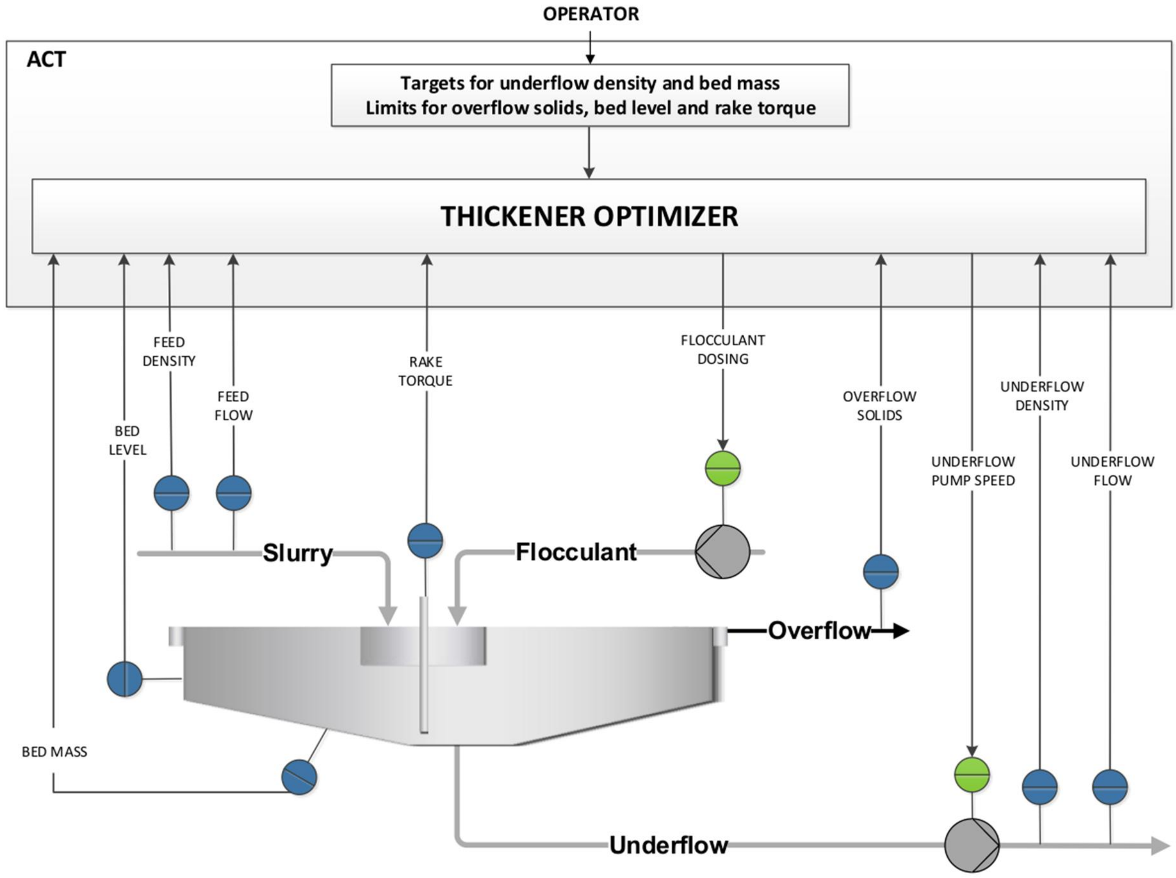


Figure 1. Structure of the controller.

Long-term follow-up (see Figure 2) shows that with the optimizing control, the Yara paste thickeners can run with underflow solids content of 66–68% to average beach slope angles[2] of 3.5 degrees (6.1%) in the tailings disposal area. Note that, the shown limits (black lines) are not used in MPC control, they just illustrate the stability of controlled solids content.

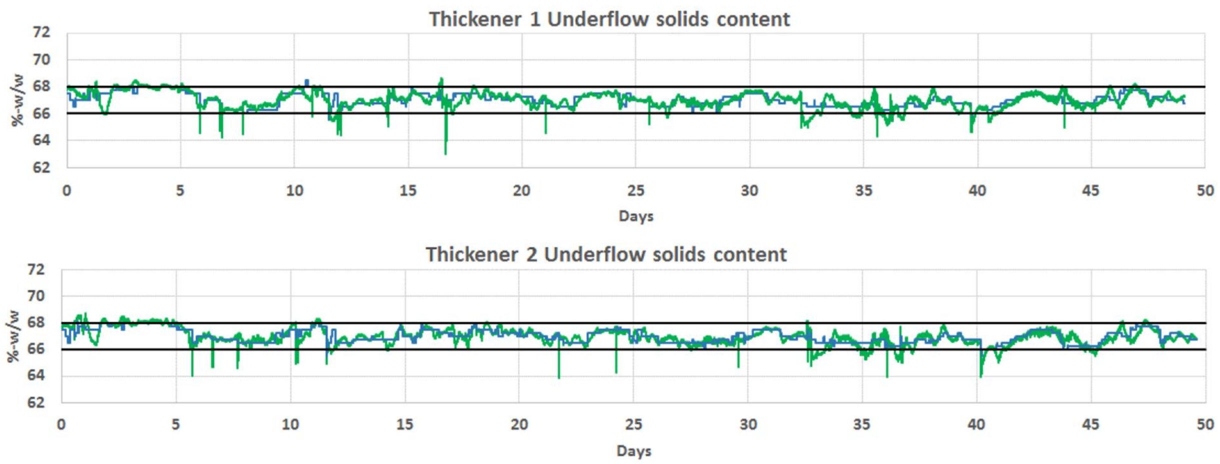


Figure 2. Long-term solids content[3] variability (*green*: measured value, *blue*: target value).

Additionally, this control system facilitates the minimum use of flocculant, which means 10-20% savings in the flocculant costs. Robust thickener operation also leads to trouble-free high-density pumping and high availability of the paste plant. One of Yara's major goals was to be able to operate the Paste Plant remotely from the main concentrator plant. Currently, the Paste Plant is fully operated remotely and only the daily process checking are done locally.

[2] Beach slope in the tailings industry refers to the surface slope of the tailings after being hydraulically or mechanical deposited from a point of discharge.

[3] Solids content calculated from the density: Cw = Ss*(S-Sl) / S*(Ss-Sl) * 100%; Cw = Concentration of solids by weight, S = Specific gravity of slurry, Sl = Specific gravity of liquid phase, Ss = Specific gravity of solids phase

Anna-Mari Wartiainen*, Markus Harju, Satu Tamminen, Leena Määttä, Tuomas Alatarvas, Juha Röning

A tool for finding inclusion clusters in steel SEM specimens

Abstract: Non-metallic inclusions, especially large or clustered inclusions, in steel are usually harmful. Thus, the microscopic analysis of test specimens is an important part of the quality control. This steel purity analysis produces a large amount of inclusion information for each test specimen. The interpretation of the results is laborious and the comparison of larger product groups practically impossible. The purpose of this study was to develop an easy-to-use tool for automatic interpretation of the SEM analysis to differentiate clustered and large inclusions information. Because of the large variety of the potential users, the tool needs to be applicable for any steel grade and application, and both for liquid and final product specimen, to analyse automatically steel specimen inclusions, especially inclusion clusters, based on the INCA Feature program produced data from SEM/EDS. The developed tool can be used to improve the controlling of the steel purity or for automatic production of new inclusion cluster features that can be utilised further in quality prediction models, for example.

Keywords: data-driven manufacturing, automated decision support, steel cleanliness, inclusion cluster analysis

***Corresponding Author: Anna-Mari Wartiainen:** University of Oulu, E-mail: anna-mari.wartiainen@oulu.fi
Markus Harju: University of Oulu, E-mail: markus.harju@oulu.fi
Satu Tamminen: University of Oulu, E-mail: satu.tamminen@oulu.fi
Leena Määttä: SSAB Europe, Raahe, E-mail: leena.maatta@ssab.com
Tuomas Alatarvas: University of Oulu, E-mail: tuomas.alatarvas@oulu.fi
Juha Röning: University of Oulu, E-mail: juha.roning@oulu.fi

1 Introduction

The inclusions are in most cases detrimental to steel quality. Inclusion characteristics, including number, size distribution, chemical compositions, shapes, spatial distribution and clustering degree, have a significant impact on steel properties. Thus, in order to learn steel cleanliness it is important to be able to analyse inclusion characteristics in steel specimen. [1–8]

A typical test specimen from a steel product contains some thousands inclusions depending on the steel and the test type. An automatic Oxford INCA feature analysis program produces more than 15 features. There is a need for an automated inclusion cluster analysis tool that enables the effective analysis of the test specimens in large scale and production of information about the most critical inclusion and inclusion cluster features.

This paper describes a novel tool for automated finding and analysing steel specimen inclusion clusters based on INCA Feature program produced inclusion data from SEM/EDS. The requirements for the tool include the applicability for any steel grade and application, and both for liquid and final product test specimens.

The tool described in this paper is the first step of a steel cleanliness analysing tool that would allow the rapid comparison of steel products and be applicable to a wide range of products. The final tool will provide a criterion for a steel cleanliness of the product applied to the whole manufacturing process.

2 The structure of the tool

For efficient usage of the tool, it is important that no additional work is needed for data preparation, especially, if a large number of specimens need to be analysed. Therefore, the tool is capable of reading the original .xlsx-files created by INCA Feature program for SEM/EDS analysed specimen and finds inclusion clusters, and provides summaries and visualisations for them. The tool can be used for testing different hypotheses and for this purpose, the tool's flexible parameter setting is especially helpful.

The tool was built with the free statistical program R [9]. The purpose of the tool is to help analysing the data INCA Feature program provides in Excel sheet for any kind of specimen, e.g. both liquid and final product specimen, for any steel grade. The features that the INCA Feature program provides in Excel sheet for each inclusion, include the centre coordinates, the area, the length, the direction, the breadth and the composition as element weight percents. The challenge is to find a trade-off between the accuracy of the modelling the inclusions and the processing time for the analysis.

Clusters are found by inspecting the Euclidean distance between the inclusions, which is the most used, simple, and easy to understand distance measure. The size, the aspect ratio and the direction of each inclusion are critical features in the distance calculation. The tool has a flexible parametrisation for the cluster definition. The distance limit for any two inclusions to be included in the same cluster is one of the parameters that the user can set. The minimum length and the minimum area of a cluster are also user specified parameter values. User may set the parameters in a graphical user interface, see Figure 1.

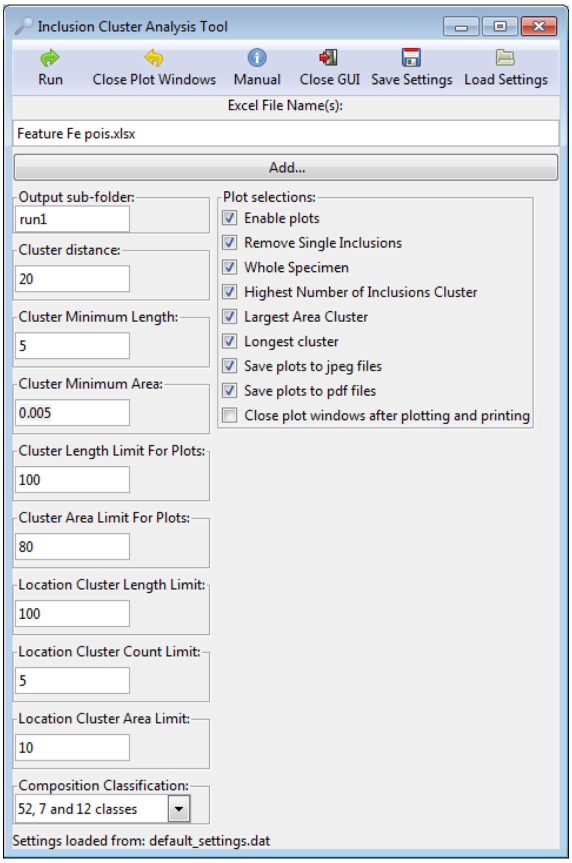


Fig. 1. Main window of the tool's graphical user interface.

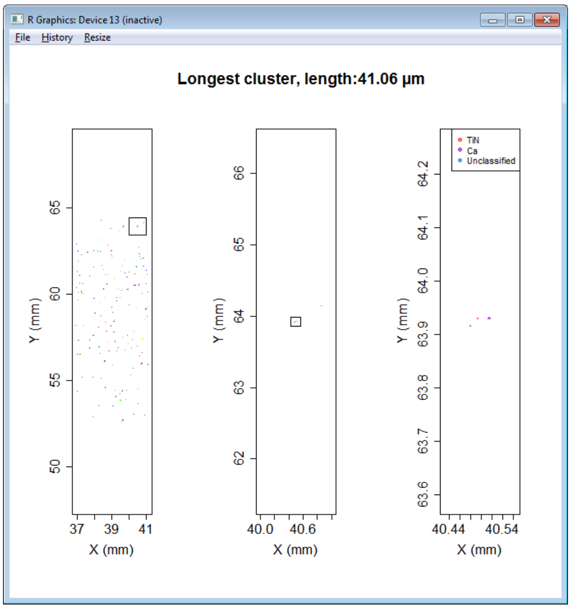


Fig. 2. Longest cluster found in the specimen.

3 Discussion and Conclusions

This paper describes a novel tool for automated finding and analysing steel specimen inclusion clusters based on INCA Feature program produced data for SEM/EDS. It provides useful cleanliness information for steel engineers by processing further the data available from INCA Feature. This tool enables the study of inclusions in general and obtaining the composition of inclusions and clusters.

There is a trade-off between the processing time and modelling accuracy. It was seen, that an adequate level of accuracy is achieved by approximating the inclusions with ellipses and there is no need for more accurate modelling for this purpose and thus, the processing time can be kept at a reasonable level. The processing time has been decreased by optimising the code and could be further decreased by eg. applying parallel processing for segments of the steel specimen.

The tool was developed in close co-operation with the end users in order to guarantee the best possible use experience. There is no additional preparation required for the original Inca Feature data sheets, which enable the simultaneous analysis of several specimens. The produced numerical information about the clusters can be utilised for steel purity grading and as also for quality prediction.

References

[1] Atkinson, H. V., Shi, G., Characterization of Inclusions in Clean Steels: a Review Including the Statistics of Extremes Methods, PROG MATER SCI, 2003, 48, 457–520

[2] Michelic S. K., Wieser, G., Bernhard, C., On the Representativeness of Automated SEM/EDS Analyses for Inclusion Characterisation with Special Regard to the Measured Sample Area, ISIJ INT, 2011, 51, 769–775

[3] Kanbe, Y., Karasev, A., Torodoki, H., Jönsson, P. G., Application of Extreme Value Analysis for Two- and Three-Dimensional Determinations of the Largest Inclusion in Metal Samples, ISIJ INT, 2011, 51, 593–602

[4] Kaushik, P., Lahmann, J., Nadif, M., State of the Art in Control of Inclusions, Their Characterization, and Future Requirements, METALL MATER TRANS B, 2012, 43B, 710–725

[5] Kaushik, P., Pielet, H., Yin, H., Inclusion Characterisation – Tool for Measurement of Steel Cleanliness and Process Control: Part I, IRONMAK and STEELMAK, 2009, 36, 561–571.

[6] Nuspl, M., Wegscheider, W., Angeli, J., Posch, W., Mayr, M., Qualitative and Quantitative Determination of Microinclusions by Automated SEM/EDX Analysis, ANAL BIOANAL CHEM, 2004, 379, 640–645.

[7] Bartosiaki, B. G., Pereira, J. A., Bielefeldt, W. V., Vilele, A. C. F., Assessment of Inclusion Analysis via Manual and Automated SEM and Total Oxygen Content of Steel, J MATER RES TECHNOL, 2015, 4, 235–240.

[8] Seleznev, M., Wong, K. Y., Stoyan, D., Weidner, A., Biermann, H., Cluster Detection of Non-Metallic Inclusions in 42CrMo4 Steel, STEEL RES INT, 2018, 89, 180026, DOI: 10.1002/srin.201800216

[9] R Core Team, R: A language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, Austria, 2018, URL https://www.R-project.org/.

Extended Abstracts
ISBN 978-952-5183-56-6

Markku Suomalainen[1,2], Ville Kyrki[2]

Learning compliant assembly skills from human demonstration

***Index Terms*—Robotics, Learning from Demonstration, Compliant Assembly, Impedance Control**

The strenuousness of programming a robot to perform different tasks is a major reason holding back the widespread use of robots in industry and at people's homes. Industrial robots are mainly used only when the same product is manufactured for long periods of times. One of the next places where the usage of robots can really increase is enterprises where production batches can be small. But to enable this step, domain experts must be able to teach the robots the required task, such that a robotics expert is not required at the stage every time the robot needs to learn a new task or fails at completing a taught task.

Learning from demonstration (LfD) is an established paradigm in robotics, where the goal is easily programmable robots. In short, the idea is to show the robot an example of a skill, which the robot learns to reproduce and generalize into other locations and similar situations. However, traditional LfD techniques struggle with compliant motions, which are required in many industrial assembly tasks.

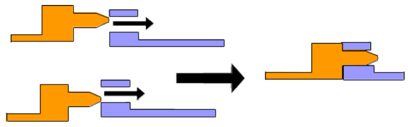
The key research question is if we can learn from human demonstrations to use compliance, contact and geometry of the task such as in Fig. 1 to mitigate pose errors with impedance controller. Humans take advantage of the environment when faced with positional uncertainties, such as inserting a screw in a poor lighting condition. The goal of my research is find methods how we can make robots learn the probing motions that humans use in uncertain situations and survive even without a vision system.

We propose to learn from human demonstration the necessary parameters of an impedance controller defined as

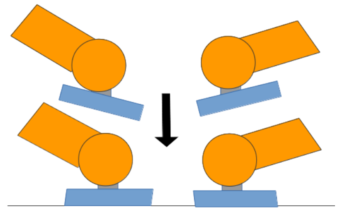
$$\boldsymbol{F} = K_f(\boldsymbol{x}^* - \boldsymbol{x}) + D_f\boldsymbol{v} + \boldsymbol{f_{dyn}} \quad (1)$$

where $\boldsymbol{x}^*$ is the desired position, $\boldsymbol{x}$ the current position, K_f the stiffness matrix, $D_f\boldsymbol{v}$ linear damping term and $\boldsymbol{f_{dyn}}$ and the feed-forward dynamics of the robot. For linear dynamics, we can compute $\boldsymbol{x}^*$ from a desired direction vector $\boldsymbol{v_d}$. To reproduce a demonstrated compliant motion, $\boldsymbol{v_d}$ and K must be learned.

In [1], we learned $\boldsymbol{v_d}$ and K by assuming we can directly measure the direction of the force which the human teacher applies to the robot in kinesthetic teaching. However, we noticed that this assumption only holds true for certain force/torque sensor configurations, and hence we wanted to solve also the more general problem, where we can only measure the force between the end-effector and the environment. We solved this problem in [2], with the observation that in a compliant sliding motion there is always a certain sector of directions from which the robot can apply force to perform the observed motion. We managed to take the intersection of these sectors in a 3-D motion, over one or more demonstrations, and thus learn the parameters for a dynamically linear compliant motion. In [3] we generalized the task to work with rotational motions as well and showed how the robot can successfully learn to mitigate orientation errors when attaching hose couplers together. Furthermore, in [4] we learned how to sequence these motions to perform a full task, such as pipeline assembly, which we also showed experimentally with a real robot. Finally, to make the robots more independent even in case of changes in the environment, in [5] we looked into whether a robot could learn to search using contact forces, similarly as a human tries to fit a key into the keyhole in darkness– we showed that we can reach acceptable levels of success in this very hard task. Finally, in [6] we showed that our method can be applied to dual-arm tasks and examined the role of compliance in dual-arm assembly with a little more detail, showing that compliance in both arms increases the performance compared to single-handed assembly.



(a) Position alignment.



(b) Orientation alignment

Fig. 1: Compliant motions can be used for aligning both position and orientation of a workpiece

To show that the method from [2] is robust enough to work with systems where errors in measurements can be higher, we combined the method with a stability-guaranteed Virtual Decomposition Control- based impedance controller for a heavy-duty hydraulic manipulator with a 475kg payload [7]. In addition to this main line of work, we explored if this kind of compliant assembly could be used even in low gravity, such as space or underwater [8].

This work was supported by Academy of Finland, decision 286580.

[1] M. Suomalainen is currently with University of Oulu, Finland markku.suomalainen@oulu.fi
[2]School of Electrical Engineering, Aalto University, Finland ville.kyrki@aalto.fi

References

[1] M. Suomalainen and V. Kyrki, "Learning compliant assembly motions from demonstration," in *Intelligent Robots and Systems (IROS), 2016*

IEEE/RSJ International Conference on, pp. 871–876, IEEE, 2016.

[2] M. Suomalainen and V. Kyrki, "A geometric approach for learning compliant motions from demonstration," in *Humanoid Robots (Humanoids), 2017 IEEE-RAS 17th International Conference on*, pp. 783–790, 2017.

[3] M. Suomalainen and V. Kyrki, "Learning 6-d compliant motion primitives from demonstration," *Robotics and Autonomous Systems*, 2018, submitted. arXiv:1809.01561.

[4] T. Hagos, M. Suomalainen, and V. Kyrki, "Segmenting and sequencing of compliant motions," in *Intelligent Robots and Systems (IROS), 2018 IEEE/RSJ International Conference on*, pp. 6057–6064, IEEE, 2018.

[5] D. Ehlers, M. Suomalainen, J. Lundell, and V. Kyrki, "Imitating human search strategies for assembly," *IEEE Robotics and Automation Letters*, 2018, Submitted. arXiv:1809.04860.

[6] M. Suomalainen, S. Calinon, E. Pignat, and V. Kyrki, "Improving dual-arm assembly by master-slave compliance," in *Robotics and Automation, IEEE International Conference on*, IEEE, 2019, submitted.

[7] M. Suomalainen, J. Koivumäki, S. Lampinen, J. Mattila, and V. Kyrki, "Learning from demonstration for hydraulic manipulators," in *Intelligent Robots and Systems (IROS), 2018 IEEE/RSJ International Conference on*, pp. 3579–3586, IEEE, 2018.

[8] S. Sharma, M. Suomalainen, and V. Kyrki, "Compliant manipulation of free-floating objects," in *Robotics and Automation, IEEE International Conference on*, pp. 865–872, IEEE, 2018.

Timo Malm*, Timo Salmi, Ilari Marstio, Iina Aaltonen

Are collaborative robots safe?

Keywords: functional safety, collaborative robots, safety requirements, levels of collaboration

***Corresponding Author: Timo Malm:** VTT,
P.O. Box 1300, FI-33101 Tampere, Finland
E-mail: timo.malm@vtt.fi

Timo Salmi, VTT
E-mail: timo.salmi@vtt.fi

Ilari Marstio, VTT
E-mail: ilari.marstio@vtt.fi

Iina Aaltonen, VTT
E-mail: iina.aaltonen@vtt.fi

Extended abstract:

Collaborative robots (cobots) have been under discussion for some years. They have properties, which make it possible for humans to work safely beside them. Cobots are expected to open up new possibilities for flexibility, productivity and user friendliness. Also, fenceless production cells are often mentioned. Collaborative robots are typically small and their reach is usually below 1.3 m and due to the size, their applications are often related to handling of small size objects. However, new applications are expected to appear.

The text shows safety design process for collaborative robots, which helps to find safety limits for the collaborative application.

One advantage of the collaborative robots is that, usually, they are easier to program and the robot workspace does not have as many objects as the workspace of an industrial robot. On the other hand, collaborative robots are used in applications, which change more often than industrial robot applications. Continuous changes make it challenging to maintain adequate level of safety. Quite often people feel that risk assessment is more difficult to make for cobots than for industrial robots, since cobots can be working beside persons.

Most of the collaborative robots are designed according to inherently safe principles i.e. they are small and power is limited. The collaborative robots are controlled and monitored so that they should not exceed the defined force, speed and area limits. The collaborative operations must apply at least one of the means: safety-rated monitored stop, hand-guiding, speed and separation monitoring or power and force limiting by inherent design or control. In old robot safety standard (ISO 10218-1:2006) there has been a general force limit (150 N), but now the limit is specific for each body part of the human according to ISO TS 15066. The power and force limiting, brings new kind of thinking, since the contact is now a designed feature and not just a rare mishap. The designer needs to estimate, which body parts can be exposed to an impact of the robot and then limit forces accordingly. One special problem with robots is that the impact (clamping) phenomenon is complex to estimate due to typically six different actuators and brakes, multitude of possible directions and locations to contact, variant loads, various speeds and multitude of cobot control parameters. Measurements at VTT with three different cobots showed that the impact forces are difficult to predict without measurements.

Figure. An example of safety measures.

One issue is that according to ISO 10218-2 section 5.2.2 safety related parts of the robots must comply with PL d and Cat 3 requirements of ISO 13849-1. This is related, among others, to stop, speed, area, power and force limiting and control. Many of the current robots do not comply with the requirements and therefore one have to consider, can e.g. a speed limit be applied to guarantee safety.

One obvious issue are the applied tools. Sharp tool is usually dangerous and the robot work area may have corners or other machines, which cause potential hazard if human body part is crushed against it. In addition, grippers may be hazardous, but there are also models, which take into account the human presence.

In addition, the level of collaboration affect the risks that the worker is exposed. The levels of collaboration can be defined as follows: no coexistence, coexistence, cooperation and collaboration. The level of risk depends on the level of collaboration, due to the exposure time and separation distance. If humans and the robot are usually not at the work area at the same time (no coexistence or coexistence), the risk for a person is not so high since the person is not exposed to danger. Typically, the risk is higher when collaboration level is high and due to collaboration, the person is working at the robot.

VTT is developing in the Business Finland funded NxtGenRob project the optimum ways to utilize next generation robotics in Finnish industry by developing solution models, design practices and (by evaluating) demonstrations from different perspectives.

Janne Saukkoriipi *, Tapio Heikkilä, Jari M. Ahola, Tuomas Seppälä, Pekka Isto

Programming and control for skill-based robots

Keywords: robot skill, programming, sensor, control

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

Co-authors: Tapio Heikkilä, Jari M. Ahola, Tuomas Seppälä, Pekka Isto: VTT Technical Research Centre of Finland Ltd,
Email: <firstname>.<secondname>@vtt.fi

This paper considers programming and control of skill-based robots. Robot skills are used to integrate and synchronize robot actions and sensor data in a consistent way. Skill-based approach provides a framework for configurable robot systems, enabling quick setups and start-ups of applications. In the paper we will introduce skill programming and skill control concepts in more details, and how they relate to usage of models and sensors (see Figs 1 & 2).

Skills are based on proper parametrization, where a set of inputs will define the whole structure of a program. Skill parameters vary with different actions: they should define the actions for all the components in a robot system (including the robot, sensors and control systems). Skill parameters can be phase dependent locations/points, poses, object ID and so on. Skills can be hierarchic and at the lowest level, there are atomic actions representing device interfaces or API functions.

The control architecture (see Fig 2) is based on proprietary and open interfaces, the latter of which are based on ROS. Proprietary interfaces are implemented for connecting devices, i.e. sensors and robot and data interfaces with ROS. Key functional components include an Object Detector component and a variety of 3D Point Cloud acquisition components (or Point Cloud sources), based on 3D cameras (based on time-of-flight or triangulation) or cooperation of a set of motion provider components (robots, transfer axis and conveyors) together with 2D laser profiler sensor components. Crosswise usage of these are supported over ROS based interfaces for 3D Point Cloud sources and 2D profiles.

As a case example, all the skills required for task “grinding with localization” are introduced. It consists of lower-level skills such as global localization with 3D-depth sensor, precise (local) localization with 2D-profile scanner and straight seam grinding. Skills are independent from each other, which means that they can be more easily used in a different task. All the designed skills are programmed in an off-line programming tool called RoboDK and implemented in a robot cell composed of KUKA KR120 R2500 PRO industrial robot with grinding tools and all the necessary sensors. With the developed skills, re-programming the paths for other seams can be made with less effort and implemented faster. Results of the grinding can be seen in Fig 3.

Eetu Heikkilä*, **Janne Sarsama**

Reliability modeling in reliability-critical system development: case wave power

Abstract: Wave power is a potential technology for producing cost-efficient renewable energy. Reliability is one of the key issues to be considered in the design of wave energy converter (WEC) devices. To address the issue of reliability, we present a proposed design approach based on reliability block diagram (RBD) modeling. Based on experiences of utilizing the RBD approach, we provide some preliminary insights on the key characteristics of the RBD approach and its suitability to WEC design.

Keywords: reliability modeling, wave power, reliability block diagram

***Corresponding Author:** VTT Technical Research Centre of Finland Ltd., E-mail: eetu.heikkila@vtt.fi

Co-author: Janne Sarsama: VTT Technical Research Centre of Finland Ltd., E-mail: janne.sarsama@vtt.fi

1 Background

Wave power is a potential technology for producing cost-efficient renewable energy. For capturing and converting wave energy, various types of Wave Energy Converters (WECs) have been developed. One of the WEC types is an Oscillating Wave Surge Converter (OWSC) that extracts energy from wave surges and the movement of water within them. OWSC has a plate, flap or some other type of element that oscillates as a pendulum mounted on a pivoted joint in response to the movement of water in the waves. OWSCs are either completely submerged or partly above the water surface. In this paper, we focus on a proposed MegaRoller OWSC concept (Fig. 1).

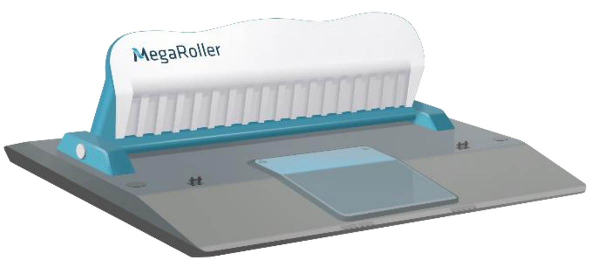


Fig 1. MegaRoller OWSC concept [1]

To achieve profitable electricity production, system dependability as a whole and especially reliability as one of its elements (see [2]) is a key issue to be considered in the design of OWSCs. Reliability is especially important because of challenges and high costs related to maintenance of such systems. In fact, it is likely that some maintenance activities of OWSC systems can be carried out only when the entire device is towed to the shore. Thus, OWSCs are typically designed for a long maintenance interval. Also, the facts that OWSCs operate in corrosive and in other ways harsh maritime environment and face substantial loads due to all possible occurring sea states, highlight the importance of reliability aspects in system design. The high degree of automation of OWSCs further emphasizes the importance of system reliability.

Reliability modeling is an approach that can be utilized to support the design of OWSCs, as well as other WEC types and other complex systems (including automation systems), to predict and improve their reliability performance. Various approaches for modeling have been proposed. The approach presented here focuses on the use of reliability block diagrams (RBDs) in modeling. RBDs describe the system as a set of interconnected blocks, representing the reliability characteristics of subsystems and individual components [3]. Each block is assigned with a probability distribution describing the block's reliability performance over time. Additional aspects, such as issues related to maintenance management, can also be incorporated in the reliability model.

2 Results & discussion

Based on experiences of applying the RBD approach in ongoing OWSC development activities, we can make some preliminary conclusions regarding the use of this approach in the context of wave power. The findings include:

– RBD modeling should be tightly interconnected with other analyses and R&D activities, starting from the early concept design phases. For example, FMECA analysis may provide guidance for focusing reliability modeling activities, and reliability modeling can provide input information e.g. for life-cycle cost calculations.

- As with all modeling, the quality of results of RBD modeling is dependent on the quality of input data. The input reliability data can be a combination of experimental data, as well as data from other sources, such as component data sheets and industry guidelines.
- RBD modeling can be applied on various levels of detail: from component and subsystem level up to the level of a fleet of several devices.
- In addition to system reliability, the modeling tools can support in comparing system designs e.g. regarding maintenance-related activities.

We see the RBD modeling approach as a potential way to assess and help improve OWSC reliability. In the MegaRoller project, the methodology will be further developed and its interconnections with other analyses in the OWSC design will be studied in more detail.

References

[1] https://www.sintef.no/MegaRoller
[2] IEC 60050-192:2015
[3] Čepin M. (2011) Reliability Block Diagram. In: Assessment of Power System Reliability. Springer, London

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 763959

Risto Tiusanen*, Timo Malm, Ari Ronkainen

An overview of current safety requirements for autonomous machines - review of standards

Keywords: autonomous work machine, standard, safety concept, safety requirement

*** Corresponding Author: Risto Tiusanen:** VTT Technical Research Centre of Finland Ltd, E-mail: risto.tiusanen@vtt.fi

Timo Malm: VTT Technical Research Centre of Finland Ltd, E-mail: timo.malm@vtt.fi

Ari Ronkainen: Natural Resources Institute Finland (Luke), E-mail: ari.ronkainen@luke.fi

Extended abstract

Background The development of automated work machine systems towards autonomous operation is proceeding rapidly in different industrial sectors. So far, automatic machines have been operating in closed areas (e.g. harbors and harbors). On the other hand, automated forklift trucks and Automated Guided Vehicles (AGV) have long been used in factories and warehouses.

Objectives The objective of the study was to obtain an overview of safety requirements for automotive non-road vehicles in different industries. The aim of the work was to explore the current situation in different industrial sectors and to study what they have in common and where there are differences.

Materials and methods VTT and Luke conducted the study on safety requirements for autonomous machines to FIMA ry. The latest information on safety requirements for the autonomous working machine systems were collected from ISO, IEC and other standards and technical reports from different industrial sectors. In addition, activities in international industry groups regarding automation and autonomy of machinery were reviewed.

Results The first safety standards or their drafts have recently been published on autonomous mobile work equipment systems. ISO 17757: 2017 [1] defines requirements for autonomous or semi-autonomous earth moving machinery and mining machinery systems. The key point in this standard is that the requirements are defined from a system-level perspective. The draft standard ISO / DIS 18497.2 [2] defines requirements for automation of agricultural machinery and tractors. The draft ISO DIS 3691-4 [3], in turn, defines the requirements for unmanned forklifts, AGVs and associated systems.

As a summary an overall picture and status of the most interesting ISO and IEC standards on the context of autonomous machinery is given in Figure 1.

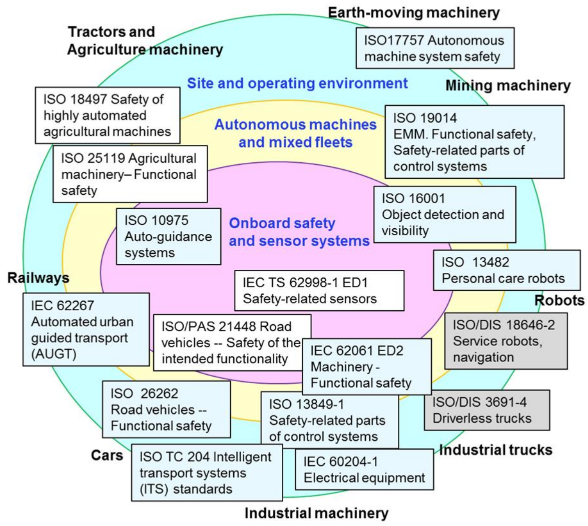


Fig. 1. An overview of the current situation in standardization on autonomous machinery.

Three approaches for safety concepts for autonomous machinery were identified in the current standardization.

The first approach aims to concepts, where machine carries a sensor system and safety system is contained within a machine. This allows non-separated working areas for humans, machines and autonomous machines to operate in the same area. These concepts are restricted to indoor applications as the sensor systems needed are only fit for indoor use.

The second approach aims to separate and isolate the autonomously operating machinery and control the access to working area and monitor other vehicles or persons in the autonomous operating area. This approach is for machines working in intensive outdoor environment.

The third approach aims to rely on monitoring by the operator. Here the concepts might include some sensing solutions to detect hazardous situations. When a problematic situation is detected, the operation could be stopped and the control is transferred to local or remote operator. The approach relies heavily on the operator's ability to understand the situation and to react correctly. The approach is suitable to working environments where there is low activity and low likelihood of hazardous situation and where there is enough time to alert the operator and transfer responsibility.

Conclusions Many of the standards related to safety requirements for autonomous machine systems are still in draft phase and the current existing standards will evolve. The standards are expected to become more precise as more is learned about the performance of the autonomous systems.

Two main problems in the standardization of safety requirements for autonomous machinery were identified. Firstly, there is a gap between the requirements set in standards and the state of the art in technology. As standards expect full compliance, there is no gradual path to develop the system. A fully functioning system is what standards expect and there is no room for trying and learning. There is problems fitting the existing designs to meet the requirements in standards. Secondly, the standards are for machine manufacturers. The worksite operators or owners are not involved. The worksite should integrate the machines not the other way round. This is also a challenge for the business case and the benefit that the machines could offer.

The systems engineering approach presented in ISO 17757 can be considered to be a good guideline to handle the management of fully autonomous or mixed fleet operation and earth moving machinery standardization is widely referenced already.

A major obstacle in the development of autonomous mobile machinery is and has been the requirements for sensor systems for detecting humans. As the machinery is heavy, collisions with the machinery pose the risk of serious injury and death, which leads to requirements for Performance Level d [4] or equal system.

Sensor fusion seems to be a good way to approach in difficult environments, since different sensors have different advantages and the sensors can compensate the weaknesses of other sensors.

References

[1] ISO 17757:2017 Earth-moving machinery and mining -- Autonomous and semi-autonomous machine system safety.

[2] ISO 18497:2018 Agricultural machinery and tractors — Safety of highly automated agricultural machines — Complementary element.

[3] ISO/DIS 3691-4 Industrial trucks -- Safety requirements and verification -- Part 4: Driverless industrial trucks and their systems. Under development 2019.

[4] ISO 13849-1:2015 Safety of machinery -- Safety-related parts of control systems -- Part 1: General principles for design.

Janne S. Peltonen*

Differences of nuclear qualified automation equipment in comparison to industrial safety automation equipment

Keywords: nuclear qualification, automation equipment, functional safety

***Corresponding Author: Janne S. Peltonen:**
Fennovoima Oy, E-mail:
janne.peltonen@fennovoima.fi

Extended abstract. This paper provides a review of the differences between nuclear qualified automation equipment and generic industrial safety automation equipment in the viewpoint of an end user and customer. Nuclear automation equipment are traditionally qualified in accordance with nuclear industry quality standards and application specific product requirements, including requirements for location of use, in which environmental conditions may include ionizing radiation and accident conditions. In the conventional process industries, generic functional safety certified automation products are preferred for safety critical applications and application specific requirements do not typically constrain the use of previously certified products.

The nuclear industry faces a challenge in modernizing aging automation systems and equipment, as well as in inviting equipment suppliers to supply their safety automation solutions (or equipment) for nuclear applications. In cases when tolerance for harsh environmental conditions is not needed, safety automation equipment developed according to industrial quality and safety standards can be equally applicable for nuclear applications. Especially the nuclear qualification process for automation equipment in Finland has been a significant contractual risk for automation suppliers. The objective of this paper is to provide comprehensive overview of automation equipment qualification requirements for nuclear power plants and current trends in the nuclear industry aiming for re-use of previously developed industrial safety automation equipment.

Methods for comparison include domain expert interviews and experiences and literature reviews, categorized in key topical areas which can be recognized based on requirements of international standards as well as regulatory and utility requirements in Finland. Simplified subjective categorization was used to be able to provide more comprehensive view.

Overview of nuclear industry equipment qualification cases and categorization of qualification areas is provided, both in organizational and technical aspects. Most important aspects such as risk based and performance based approaches, probabilistic and deterministic approaches, safety classification, functional design bases, layers of protection, technical architectures and diversification and environmental conditions are compared in generic terms. Comparison is made to requirements for safety automation equipment in the conventional industry. Specific requirements for software-based equipment qualification requirements are highlighted, including also the emerging cyber security aspect. Utility owner responsibilities and activities, organizational requirements for suppliers and conformity assessment, permitting and licensing related activities are included in comparison.

The result of the overview identifies the specific requirements for qualification of automation equipment in the Finnish nuclear industry, which are part of an equipment qualification process and potentially not adequately covered in generic functional safety approaches in the conventional industries. The qualification and licensing process for automation equipment in the nuclear industry is discussed and differences to the conventional industry practices are highlighted. Finally, the significant elements to be considered in an equipment nuclear qualification process for conventional industry equipment are proposed based on the study.

References

[1] Palo M, ÅF, Tuominen J., Fennovoima, Hassinen K., TVO, Pajunen L., Fortum, Jokineva H., Fortum, Pöytäniemi J., Fortum, KELPO – Development of the licensing and qualification processes for the systems and equipment of nuclear facilities in Finland - Final report, 29 January 2019

[2] Arndt S. A., Use of IEC and Other Alternative Standards in NRC Reviews (presentation), U.S. NRC. In: ANS 11th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies NPIC-HMIT 2019, February 2019

[3] Hendricks J. R., Commercial Grade Dedication – Digital Systems and Software (presentation), Curtiss Wright Nuclear. In: ANS 11th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, Digital I&C Workshop, NPIC-HMIT 2019, February 2019

[4] Nevalainen R., Varkoi T., Process Assessment Method for the Nuclear Power Domain, Nuclear SPICE Handbook 1.0, FiSMA report 2018-1, 26 November 2018

[5] Peltonen J. S., Functional approach to nuclear qualification of automation, Fennovoima. In: ANS 11th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies NPIC-HMIT 2019, February 2019

[6] IEC 61508-1:2010, Basic Safety Publication – Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements, International Electrotechnical Commission, Geneva, 2010

[7] IEC 61513:2011, Nuclear Power Plants – Instrumentation and Control Important to Safety - General Requirements for Systems, International Electrotechnical Commission, Geneva, 2011

[8] IEC/IEEE 323-60780:2016, Nuclear facilities – Electrical equipment important to safety – Qualification. IEC/IEEE, Geneva, 2016

[9] IAEA, Safety Standards – Specific Safety Guide No. SSG–39 – Design of Instrumentation and Control Systems for Nuclear Power Plants, The International Atomic Energy Agency, Vienna, 2016

[10] STUK, Guide YVL E.7 – Electrical and I&C equipment of a nuclear facility, Radiation and Nuclear Safety Authority STUK, Helsinki, Finland, 15 March 2019

[11] IEC 62671:2013, Nuclear power plants – Instrumentation and control important to safety – Selection and use of industrial digital devices of limited functionality, IEC, Geneva, 2013

Matti J Huotari*, Kari Määttä, Teemu Myllylä, Juha Röning

Photoplethysmography signal analysis to assess sauna exposure, arterial elasticity, and recovery

Keywords: arterial elasticity, photoplethysmography, pulse wave analysis, sauna exposure

***Corresponding Author: Matti Huotari,** University of Oulu, E-mail: matti.huotari@oulu.fi,

Co-authors: Kari Määttä, Teemu Myllylä, Juha Röning, University of Oulu, E-mail: firstname.surname@oulu.fi

1 Introduction

The basic biomedical information on illnesses is increasing, however, diseases like arteriosclerosis (AS) is becoming a common cardiovascular disorder among elderly people, especially in females. It is predicted that the negative impacts of AS on young people can be greater than on the elderly people in the long run. Degenerative changes in the vascular tree have many causes in addition to the life style. Arterial elasticity (AE) would provide a direct indicator for cardiovascular healthiness and predict AS. Photoplethysmography (PPG), and especially its response pulse wave decomposition, envelope analysis, and its second order derivative (SDPPG) opens us to determine the instantaneous heart rate (IHR) which is used to seeing on fitness equipment, sports watches, and consumer heart rate devices.

The hemodynamic responses to the sauna exposure have specific effects which are not caused by one single stimulus. The responses, which are caused by the sauna exposure, can depend on thermoregulatory responses, age, gender, the circulatory and respiratory system, as well as traditions related with the exposure time and temperature of the Finnish sauna [1, 2].

PPG measurement receives interest because of the simplicity, but the difficulty of adjusting parameters restrict applications. However, its second order derivative (SDPPG) opens us to determine the instantaneous heart rate (IHR) which is $60/(t_{An-1}-t_{An})$ where t_{An} is the n^{th} A peak of SDPPG. The sauna exposure can be recommended mainly in order to easier recover after physical exercise, and the various pain problems. The sauna exposures in long term effect on the motion system increases arterial elasticity. It reduces the viscosity of the blood so that blood flowseasier and increases diameters of blood vessels and the joints' mobility. The IHR and variation of arterial elasticity with blood pressure are caused by the sauna exposures on healthy subjects. Regular sauna bathing is shown to be protective from cardiovascular disease [2, 3]. Our vascular system responds to interval training, especially by the sauna exposures the body to heat alternating between sauna heat and normal temperatures, the arteries are stimulated to expand and contract.

2 Method and Subjects

Accurate determination of start and peak of a PPG signal plays a central role in arterial stiffness, instantaneous heart rate, and its variability. For analysis of four PPG signals correspond to each other perfectly at a given frequency, as in the case of finger IR (infra red) and red LED. In PPG technology, the main difficulty is its quantitative analysis. PPG based on phase sensitivity technic has proved very good. In our measurements the light intensities and wavelengths (red 640 nm & infrared 920 nm) are fixed. The studies were approved by the ethical review boards of the Oulu University, University Hospital, and the Finnish National Supervisory Authority of Health and Welfare (VALVIRA). Our needs to analyze the signal on a case by case basis we don't have the proper automatic measurement and analysis system. For automated clinical diagnosis based on PPG would be also important in the future healthcare.

3. Results and discussion

The heart rate increased almost linearly in many cased during the sauna exposures. In each case, it is important to have the same resting period. It would be difficult that all the subjects arrive at 8 in the morning to the sauna, and we have no parallel measurement system.

References

[1] Peltokangas, M, Vehkaoja, A, Huotari, M, Verho, J,Mattila, VM, Röning, et al. (2017). Combining finger and toeotoplethysmograms for the detection of atherosclerosis, Physiological Measurement, 38, (2).

[2] Wessapan T, Rattanadecho P (2015) Heat transfer analysis of the human eye during exposure to sauna therapy, Numerical Heat Transfer; Part A: Applications.

[3] Kamioka H, Mori Y, Nagata K, Iwanaga S, Uzura M, Yamaguchi S (2019) Relationship of daily hot water bathing at home and hot water spa bathing with underlying diseases in middle-aged and elderly ambulatory patients: A Japanese multicenter cross-sectional study, Complementary Therapies in Medicine, Volume 43, Pages 232-239.