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Balancing intended collaboration and safety requirements during the design and implementation of an industrial cobot application - A case study

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Abstract. The aim of this article is to illustrate, through a real-life case study, the importance of balancing the intended human-robot interactions and occupational health and safety (OHS) requirements when designing and implementing a collaborative application involving industrial robots (in the sense of ISO 10218). This article discusses the obstacles and efforts involved in achieving greater but safe collaboration by chronologically detailing the risk reduction approach.

A consortium of manufacturers commissioned the National Research Council Canada (NRC) to implement a TRL-5 cyberphysical finishing cobotic platform for companies of the metal industry. By finishing, we mean polishing, grinding and deburring tasks on metal parts. While the cobot performs the finishing tasks, the human operator supervises the process, oversees the quality control of the parts and indicates which production lot should start. The main reasons behind the consortium's request were: 1) the need to alleviate the musculoskeletal disorders among the finishing operators, 2) the labor shortage and 3) a drive to innovation. The robotic platform consists mainly of a support table with a dust extraction system, a 6-axis cobot arm attached to a rail to add a 7th axis, accessories and tools for part finishing (e.g. compliance head, abrasive discs). The industrial robot used was a UR10 cobot.

One of the initial objectives was for the finishing platform to be collaborative to ensure flexibility and fluidity of operations. Typically, a needs analysis and a risk assessment help determine the feasibility and the usefulness of a collaborative application. However, in the case of the NRC's laboratory application, a different approach was taken. The pursuit of innovative solutions to increase flexibility in finishing activities required to push the limits of technology and to explore what is achievable and what is not. In fact, such an approach is frequently employed in the industrial context. Thus, an iterative risk assessment was carried out once the platform structure has been assembled.

First, fifty-five risks have been identified, including mechanical risks coming from the cobot arm movements and the disc rotation. Regarding those mechanical risks, the protective measures the OHS team suggested to allow the operator to be close to the functioning cobot were 1) a reduced speed of the moving cobot arm to 16 mm/s (PL = d, category = 3), 2) a protective stop, of the moving arm, triggered by a PLe, cat. 3 Airskin "sensitive skin" in the event of contact, 3) PLe, cat. 4 emergency stop buttons and 4) a protective stop, of the rotating disk, triggered by two PLd, cat. 3 laser scanners in the event of intrusion into the safeguarded space. Personal protective equipment (PPE) has also been suggested. The residual risk was then considered acceptable only if the disc was at a standstill.

However, the protective measures concerning the rotation of the disc conflicted with the collaborative application intended by the consortium and the expressed need to approach the rotating disc during finishing to perform a visual quality control of the part (operator positioned approximately 200 mm from the tool). As a result, the solution proposed by the OHS team at this new stage was to allow access to the zone using a dead man's switch (DMS) to bypass the scanners' protective stop, combined with wearing close-fitting clothing, tying back hair, and wearing PPE to protect against the risk of projections and gloves to protect against the risk of cutting with the disc. Wearing gloves was intended to reduce residual risks since contact with the disc remains possible (e.g. free hand, inertia of the disc to stop). To verify the actual hand protection provided by gloves, five models offering high mechanical resistance were tested with two abrasive discs in different configurations. The tests consisted of rotating the disc at 9,000 rpm (operating speed), bringing it close to the glove at a speed of 17 mm/s with the cobot arm, then touching the glove for a fraction of a second to simulate unexpected contact (withdrawal of the arm when the force sensor measures 70 N in contact with the support inserted into the glove). The results were unequivocal: all gloves were cut or torn. Thus, wearing gloves will not protect the operator in the event of contact with the rotating disc on the finishing platform.

In the end, the protective measures proposed when the disc is rotating (i.e. scanners + DMS + PPE) can be considered acceptable for setup or teaching as described in clause 6.2.11.9 of ISO 12100:2010. This is the case during the implementation of the platform. However, it will not be sufficient for industrial use. According to clause 5.5.5.3 of ISO/TS 15066:2016, “parts which could cause injury shall not be present in the contact area” with the robot. For the platform to be considered collaborative in production, with the intended human-robot interactions, research and development still needs to be carried out. Avenues to explore include 1) more precise monitoring of the area around the disc (e.g. sufficiently reliable vision system) coupled with a dedicated brake on the disc, 2) a disc protector adapted to the constraints of the process, 3) programming safe trajectories by following pre-established rules (e.g. order and direction of arm deployment, favouring trajectories of the disc when finishing towards the centre of the table rather than towards the outside) and 4) keep the operator out of the zone when the disc is rotating whenever it is possible by using other options (e.g. miniature camera fixed on the compliance head for inspection).

In conclusion, this project illustrated how the intended level of collaboration and OHS risk management requirements must be considered together when designing and implementing such an application to deliver the desired level of flexibility. In this case, the potential OHS issues were highlighted early in the project, enabling the team to address it through innovation.

Keywords: collaborative robotics, intended human-robot interactions, residual risk, robotic tool, rotating disc

Comparing cybersecurity and functional safety risk assessments

Timo Malm (VTT), Risto Tiusanen (VTT) and Josepha Berger (VTT).

Abstract. As number of cyberattacks have increased, safety systems in machines can also be endangered. Risk assessment is one way to identify and assess the threats and vulnerabilities of safety related systems. Safety risk assessments have already a long tradition in machinery sector, but cybersecurity assessments have a shorter history and good practices need to be developed.

There are many new standards, requirements and proposals, which give guidelines for cybersecurity. New Machinery Regulation (EU) 2023/1230 of June 2023 gives some cybersecurity requirements, which were not in the current Machinery Directive (2006/42/EC). Other new requirements will be set, for example, in Network and Information Security Directive II, in Data Act and in Cyber Resilience Act. There are also some cybersecurity standards related to industrial automation and machinery, such as, IEC 62443 family (automation), IEC TS 63074 (functional safety, machinery) and ISO/TR 22100-4 (machinery). The number of new requirements and guidelines show that cybersecurity domain is developing, and all processes are not yet mature compared to safety and functional safety engineering processes.

The main objective of the study is to find out is it practical to merge completely or partially cybersecurity and safety risk analyses or does it just increase work. Another objective is to point out phases of the cybersecurity and safety analyses, when cooperation increases effectiveness of the analyses.

The primary objective of safety analyses is to avoid accidents and the primary objective of cybersecurity analyses is to prevent or minimize the effects of cyberattacks. The causes of functional safety failure are random failures or design/systematic (e.g. software) faults, whereas cybersecurity failures are related to intentional attacks, which exploit vulnerability. Safety risk victim is typically the system user, whereas cybersecurity victims are often many stakeholders. These factors show that the basis for cybersecurity and safety analyses can be different and therefore it is more practical to keep the analyses separate.

Risk assessment tries to find also critical, but improbable failures/risks, kind of “devil in the details”. The question is: Can these kinds of risks be found in separate cybersecurity and safety analyses or in one single merged analysis. In separate analysis same amount of resources could give more focused analysis, which can reveal more weaknesses. On the other hand, if “the difficult to find” risk were between safety and security, then discussions with safety and security analysts could reveal the risk. This means that discussions with safety and security analysts are needed both in merged and separate analyses.

In bottom-up approach (e.g. failure mode and effects analysis, FMEA) all details are analysed systematically and the result can give good confidence on finding single-point failures/cases. In bottom-up analysis each item is analysed, and it causes a lot of work, if both safety and security factors are estimated for each item. The analysis is thorough, but often not very effective. Top-down approach (e.g. fault tree analysis, FTA) begins with top event and the initial causes are concluded. All causes and items are found according to the knowledge of the analysts, but the items are not found systematically. Top-down methods can merge simultaneous failures/events/cyberattacks and it can give a good overview of the risks.

In this study cybersecurity and safety risk assessment processes have been compared to see similarities of the analyses and which phases have mutual interests. In all risk assessments perhaps the most important phase is risk/vulnerability/threat identification. Unidentified risk is not under control or actually it increases uncertainty of the risk. Identified risks should be known as potential input in other analyses to increase the possibility to identify hazards. Cooperation between analyses is important also in other phases in order to estimate and evaluate relevant risks and to avoid conflicts between objectives.

The main objectives of functional safety are to maintain integrity and, in many cases, also availability of the control system. The main objectives of cybersecurity are to maintain integrity, availability and confidentiality. Confidentiality is not considered in functional safety, since it has no straight connection to accidents. In many cases, detected jeopardized safety integrity (e.g. failure) causes machine stopping, which may violate security objectives (reduced availability). Different objectives of cybersecurity and safety analyses is one reason to keep the analyses separate. However, it is important to compare safety measures and security countermeasures to match adequately both cybersecurity and functional safety objectives.

This research has been conducted as a part of the Connected Mobile Machine Lifetime Cyber Security (COMMA) project, which is mainly funded by Business Finland.

Keywords: Risk assessment, cybersecurity, functional safety, safety of machinery

Safety in human-robot interaction - IEC TS 62998 series as companion standard

Martin Wuestefeld (SICK AG)

Abstract. The ability of robots to interact with their environment is an essential capability, especially when humans are present in the environment. Knowledge about the presence of humans and the environment is usually obtained through sensors. Physical properties of objects are transferred with sensing technologies ,as part of sensor devices, into data provided at their outputs under the increasing use of complex algorithms. The sensor data are used as basic information in different types of controls systems performing as edge device up to cloud systems. The combination of sensor device and control systems architectures information are used in perception functions in robotics to perform tasks such as material handling or to achieve safety in human-robot interaction.

Within the presentation, the IEC TS 62998 series of standards will be discussed in the context of such perception systems. This series of standards is well suited to specify, design and evaluate such perception systems for robotics in a safety-oriented manner. With the publication of IEC TS 62998-3 in August 2023 (safety-related sensors used for the protection of persons: part 3 sensing technologies and algorithms), more detailed requirements for the implementation of algorithms or the use of machine learning models are given. Machine learning enables the efficient use of real, practical data for the design of such safety-related, sensor-based systems. In combination with general patterns of use , also named the intended use, a more generic methodology is provided that open up the combination of deterministic intentions with data from the practice. In addition, requirements on a wide range of different sensor technologies is given that support their evaluation for the detection of e.g. persons and the dependability of the detection under environmental conditions. The range of sensor technologies that can be used in this context spans a broad range of known state of the art. From 1D-2D-3D optical sensors, ultrasound, radar to UWB or 5G technologies.

In combination with the already in 2019 published IEC TS 62998-1, with general requirements for Safety - related Sensors used for the protection of persons, there are now 2 Technical Specifications available which in their combination give more detailed help without being design specific limiting for the use of technologies. A set of requirements, related to functions performed by safety-related sensors, for design and development can be derived from risk- assessments either in accordance to general standards (e.g. ISO 25100 or IEC/ISO 31000) or machine type specific ones. By this single machines like robots in industrial or construction machinery, group of machines or complete plant’s can make use of safety-related sensors or sensor systems in accordance to IEC 62998.

A Key Take aways of the presentation is the use of IEC TS 62998 series for the design and the development of robotics perception systems that will be used for safe human-robot/machinery interaction. The increasing need to handle human and energy resources gently while maintaining safety will accelerate the development of interacting machines and systems.

Keywords: autonomous machines-cobots safety, methodologies, design rules&strategy, AI&safety, standardization

Application example: Evaluation of mechanical collisions at workplaces with collaborative robots

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Abstract. Over the past decade, the German Social Accident Insurance (DGUV) has supported studies in which empirical limit values for mechanical collisions were determined. In addition, the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) and Fraunhofer IFF have presented a methodology used to determine biomechanical corridors for 24 different body parts. New stiffness parameters can be derived from these corridors, which are to be used in measurement devices to check compliance with the empirical limit values. A summary of this work will be given in the presentation.

An application example will show how the values can be interpreted and applied in practice. In a risk assessment at workplaces with collaborative robots, it is often determined that hands and arms are in the hazard zone. Therefore, the study shows how an analysis was carried out on three lightweight robots for collaborative use and which results were achieved.

In addition, the IFA has provided a practical solution 'Practical Risk Assessment Guide for Workplaces with Cobots: Conversion of Biomechanical Limit Values' that enables safe and simple validation with already existing measuring devices. A new ISO/PAS 5672 supports the comparability of measurements worldwide.

The work also indicates how standardization can use a simplified safety diagram to provide easy, practical solutions to ensure the safety and health of workers.

Keywords: mechanical hazards, collaborative robots, safety validation, ISO 10218, ISO/TS 15066

Smart mining and emerging occupational health and safety risks in the mining industry: A literature review.

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Abstract. Introduction: Progress and advanced technologies continually enhance productivity by automating tasks and optimizing resource utilization, fostering innovation and competitiveness in various industries. Smart mining technologies, amalgamating automation, data analytics, and the Internet of Things (IoT), epitomize a pivotal evolution in mining. Automation, curtailing human exposure in dangerous zones, converges with data analytics and IoT for real-time monitoring, fundamentally reshaping traditional approaches.

Occupational Health and Safety (OHS) in mining is gaining heightened significance due to evolving industry dynamics. The imperative to ensure worker well-being amid technological advancements and operational complexities underscores the growing relevance of robust OHS measures in the mining sector.

Automation, by minimizing human presence in high-risk areas, significantly reduces the likelihood of accidents, fostering a safer working environment. Predictive maintenance ensures equipment reliability, preemptively addressing potential failures that pose risks to worker safety. The real-time monitoring capabilities enable swift responses to safety hazards.

Yet, as these transformative technologies integrate, challenges emerge. The intricacies of technology integration may lead to initial disruptions, urging meticulous planning for seamless transitions. The reliance on advanced technologies introduces new dimensions of vulnerabilities, underscoring the imperative for robust protective measures.

In this landscape, the industry seeks an equilibrium—leveraging transformative benefits while addressing emerging challenges. This equilibrium is a technological and a strategic imperative.

A comprehensive awareness of the advantages, particularly in enhancing OHS, allows for targeted implementation strategies that prioritize worker well-being. Simultaneously, a thorough understanding of the challenges enables proactive planning and risk mitigation.

Method: This paper presents the findings of a systematic literature review on smart mining and emerging OHS risks, employing the PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The approach involved a comprehensive research strategy, selecting four databases—Scopus, IEEE Xplore, ScienceDirect, and PubMed—due to their extensive coverage. The timeframe was not restricted to ensure inclusivity of relevant literature. Emphasizing the breadth of coverage, the focus was primarily on reviews and research articles. The decision to include both English and French languages aimed at capturing a diverse array of publications.

Emphasizing keywords such as "safety and health" "technology," and the mining industry, the review encompassed an examination of 236 papers sourced from primary digital libraries. Following the PRISMA guidelines, 32 articles were subsequently chosen for in-depth analysis.

Finding: This paper conducts a comprehensive review of mining technologies within three distinct categories: automation, Industry 4.0, and Industry 5.0. In parallel, a focused exploration of OHS is undertaken in two key dimensions. Firstly, the analysis delves into how technologies contribute to OHS, encompassing monitoring, detection, control, and reduction of hazards.

Secondly, the paper addresses the impact of technology on miners' health and safety, examining both positive and negative aspects. This dual perspective aims to present a nuanced understanding of the intricate relationship between technological advancements and the well-being of miners. The study not only identifies potential solutions offered by technology but also critically evaluates their repercussions.

A meta-analysis is employed to synthesize findings, considering parameters such as field, publication source, publication year, geographical location, hazard types, technology types, and the specific focus on OHS. This comprehensive approach allows for a better understanding of the nuances and patterns within the existing body of literature.

The findings are categorized into six distinct groups within the surveyed field: accidents, safety management, ergonomics, chemical agents, physical agents, and legislation. This classification sheds light on the multifaceted nature of OHS concerns in the mining industry.

Conclusion:

This paper reviews mining technology, offering a comprehensive overview that aids experts, practitioners, and affiliated organizations in identifying blind spots, gaps, overlooked issues, identifying new hazards, and areas of ambiguity within the field. By expanding the collective vision, this analysis serves as a valuable tool for scrutinizing and verifying existing knowledge. It also facilitates the formulation of strategic proposals to address identified concerns, fostering a proactive approach to tackling challenges in the dynamic landscape of mining technology.

Keywords: smart mining, technology, automation, emerging risk, OHS

Cyber risk and machine safety: towards the integration of cyber risk assessment into occupational risk assessment?

Pascal Lamy (INRS), Nellie Perrin (INRS) and Nisrine Ghadban (INRS).

Abstract. With the industry of the future or Factory 4.0, production systems and machines are becoming connected elements, either through the company's information system, or because they are directly linked to the Internet. This connectivity increases the attack surface for a cyber-attack. It opens the door to a new playground for hackers, more accustomed to attacking the company's "classic" information system. This opening could have an impact on the safety of machine putting workers in danger.

Generally speaking, cybersecurity is aimed at protecting assets or the manufacturing process, and the occupational risk aspect is not often mentioned as a risk as a result of a cyber-attack. The mention of an occupational risk for industrial machinery is relatively recent. However, the publication of machine regulation 2023/1230, which will come into force in 2027 within the EU, introduces malicious acts into the essential health and safety requirements, which will require them to be taken into account. The identification of machine faults due to cyberattack is the subject of a growing body of work, with university studies showing the impact on health and safety in the workplace.

INRS has launched a study to develop a cyber risk analysis method dedicated to machines, and to investigate how this cyber analysis can be integrated into occupational risk assessment. The first stage of this study is to take stock of the situation in companies in terms of machine connectivity. With the help of an occupational ergonomist and psychologist, we are currently conducting a survey using questionnaires to gather information on machine connectivity, on company practices in terms of cybersecurity, as well as workers' perceptions of the risk of cyber-attack and its impact on their health and safety. The structure of the questionnaires was validated using pre-tests on samples of target audiences: production staff, IT service staff and staff in charge of methods or maintenance. These anonymous questionnaires are in electronic format, making them easy to distribute within companies. The survey is currently underway and will continue throughout the first half of 2024.

This paper will present the structure of these questionnaires and the hypotheses we wish to test. It will go on to describe how the results of this survey will be exploited in further work, and explain the various stages envisaged as part of this study.

Keywords: cyber risk assessment, connected machines, cybersecurity

Defeating of Protective Devices: Results of a Recent Survey

Stefan Otto (Institute for Occupational Safety and Health of the German Social Accident Insurance).

Abstract. Protective devices are repeatedly being dismantled, bypassed or otherwise rendered ineffective, resulting in thousands of severe work accidents every year. A study published in 2006 showed that one third of all safeguards on metalworking machines are defeated [1]. The results urged occupational safety and health (OSH) professionals to act. Meanwhile the issue is increasingly being taken into account in regulations and standards. However, accidents due to defeating continue to occur, and OSH experts across all industries report ongoing tampering with machines.

To assess the current extent of the problem, the Institute for Occupational Safety and Health of the German Social Accident Insurance conducted a survey among 839 OSH professionals. The findings indicate that across all industries a quarter of all machinery is being defeated. The survey also shows that bypassing protective devices is tolerated by supervisors more often than expected, which leads to a statistically significant increase of defeated safeguards and subsequent accidents. The results of the survey are discussed in this paper. Further resources that help to tackle the problem are presented.

[1] Apfeld, R.; Huelke, M.; Lüken, et al., Manipulation von Schutzeinrichtungen an Maschinen, Hrsg.: Hauptverband der gewerblichen Berufsgenossenschaften (HVBG), Sankt Augustin 2006.

Keywords: defeating, tampering, bypassing, protective device, safeguard, safety culture

Assessing an automated mining operation with STPA

Josepha Berger (VTT), Risto Tiusanen (VTT) and Timo Malm (VTT).

Abstract. Autonomous mining reshapes contemporary mining practices as it plays an increasing role in bringing value to customers. The benefits encompass improvements in operational efficiency, safety, and process reliability while offering flexible maintenance programs that reduce downtime and costs. Mine automation systems cover a wide range of automation, from individual equipment to controlling entire fleets. However, the growing complexity and functionality of these systems introduce new risks, necessitating a comprehensive safety analysis. Traditional hazard analysis methods, which examine system components separately and in isolation, are no longer adequate. In complex systems, such as mine automation systems, losses may not only occur due to component failures but rather as a result of unpredictable and undesired interactions among system elements. Rooted in system theory, Systems Theoretic Process Analysis (STPA) is capable of addressing this complex, non-linear way of how losses can arise.

This study employs STPA to examine its suitability for the mine automation industry by assessing a mining pit's automated and remotely operated drill rig fleet. Additionally, the research explores the potential of STPA as a valuable tool for identifying system requirements and safety goals in the context of mine automation systems. System elements of the examined use case are three automated drill rigs and a teleoperation station. The analysis deals with a typical daily maintenance use case when the mode of operation must be changed as the maintenance person approaches the drill rig and returns.

STPA, is implemented in four stages: defining the analysis' purpose, modelling the control structure, identifying the unsafe control actions, and finally describing loss scenarios. In comparison to traditional hazard and safety analysis tools, STPA gives special attention to control actions by dedicating Step 3 to the identification how assumingly suitable and safe control actions can become unsafe.

Results show that STPA, which views safety as a control problem, provides valuable insights into the dynamic interactions between the remote operator and the on-site maintenance personnel using the drill rig's onboard control system and the equipment at the site and in the teleoperation station. The analysis of six use-case control actions revealed 15 possible unsafe control actions and over 40 possible loss scenarios. Compared to other STPA analyses, these findings are relatively limited in quantity. This may be attributed to the narrowly defined use case and the restriction to analysing only six control actions. A significant share of loss scenarios is related to human machine interactions. Leveraging available methodologies on mental models could have possibly led to an even higher amount of loss scenarios, especially related to human machine interactions. Concretely, the study highlighted the importance of communication between the maintenance person and the remote operator, emphasizing the need to prevent communication and connectivity problems. Additionally, challenges related to the indication of the operating mode of the drill rig and its transition as well as the location of on-site equipment affecting safety were identified. Proposals were made for clearer communication through clearer operating mode indication. Further, better site overview and visibility could prevent unintended drill rig approaches during drill rig's automatic operation. While the results are not of technical nature, they can aid in creating a safe work environment and understanding factors affecting the work on site. STPA proved to deliver valuable input for discussions during system's conceptual design phase. Furthermore, the tool appears to contribute to assessing planed system design modifications as well as reassessing already existing systems.

This research has been conducted as a part of the "Future Electrified Mobile Machines" (FEMMa) project, which is mainly funded by Business Finland.

Keywords: Systems Theoretic Process Analysis, mine automation industry, system safety

Effects of various factors on Power and Force Limitation function of collaborative robots

David Tihay (INRS) and Adel Sghaier (INRS).

Abstract. The implementation of a collaborative robot applications and the resulting man-robot proximity can give rise to a number of risks, including the risk of impact and crushing for operators or third parties moving around in the robot's environment. Various means of protection are available to integrators to limit the effects of possible contact between man and robot, including the power and force limitation function (PFL). This is a function built into the robot that enables it to stop its movements when a collision is detected.

There are various technological solutions available for achieving this function. Some robot manufacturers use force sensors that are located on each of the robot's joints, while others use a single sensor that is positioned under the robot's base. Another approach is to measure the current drawn by the motors to determine whether there has been a collision. Regardless of the technology used for power and force limitation, manufacturers of collaborative robots implement it as a safety function.

It is possible to adjust the level threshold of this safety function by changing numerous parameters (threshold value for force, moment, acceleration, power, etc.). Consequently, integrators find themselves faced with a complex choice of parameters.

Diversities of technologies used by manufacturers and their possible limitations, as well as the difficulties encountered by integrators in setting parameters led INRS to conduct a study identifying the factors that may affect the PFL function. To address this issue, a dedicated test bench was designed to be compatible with a wide range of collaborative robots. This experimental facility enables the simulation of human-robot contact scenarios in different robot trajectory profiles, while varying the parameters of the PFL function. The objective of this experimental installation is to :

- measure the real values of the forces involved in different human-robot contact situations using a dedicated Power and Force Measurement Device,

- ensure that the measured force values do not exceed the threshold values programmed into the robot (based on the theoretical values as defined in the technical specification ISO TS 15066),

- identify the factors, including the robot's configuration parameters and trajectories, that may have a potential significant impact on the PFL safety function, resulting in a variation on the measured force value.

In this study, two collaborative robots of the market using different PFL technologies and widely used in the European industry were tested. This article presents the results of measurements conducted on those robots in both constrained (quasi-static) and unconstrained (transient) contact situations. These experiments were conducted by employing the 'one factor at a time' methodology, wherein force measurements were carried out by successively varying all the adjustment parameters accessible by the user. Moreover, these experiments were carried out for different trajectories of the robot. This article provides details of the test protocol used to carry out the force measurements and analyses the impact of different parameters and trajectories of the robot on the behaviour of the PFL function. Finally, this article proposes caution’s point and gives recommendations on how to integrate a collaborative robot application, and on how to measure human-robot contact force.

Keywords: collaborative robot, power and force limitation, collision sensor

Design Requirements Related to Human Information Processing for Detecting People on Camera-Monitor Systems (CMS) of Mobile Machines

Peter Nickel (Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA)), Shuaixin Qi (Swiss Federal Institute of Technology Zurich (ETHZ)) and Marino Menozzi (Swiss Federal Institute of Technology Zurich (ETHZ)).

Abstract. To prevent accidents, machinery design should allow operators to monitor hazard areas of machinery. If direct view into hazard areas of mobile machinery is obscured by parts of the machine, indirect vision shall be provided, e.g., by mirrors or camera monitor systems (CMS). Scientific findings from human factors and ergonomics, accident reports, and practical working conditions suggest that specifications in international standardisation for the height of person representations on monitors of CMS are insufficient at 7 mm. In a research project funded by DGUV, the Human Factors Engineering Group at ETH Zurich is investigating the height of person representation on monitors of CMS to ensure safe detection under realistic working conditions. Initial information on the project is available (https://www.dguv.de/ifa;/forschung/projektverzeichnis/ff-fp0472-2.jsp). The given paper will give background information, inform about initial project activities and provide an outlook into prospective empirical laboratory, simulation, and field studies. For more information, please see draft "sias2024-PePaKaMS-b.pdf".

Keywords: Human-System Interaction, Human-Maschine Interface Design, Camera-Monitor System, People Detection, Assistance System, Human Factors and Ergonomics, Machinery Safety

Design of work equipment according to human factors and ergonomics for machine and system safety

Peter Nickel (Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA)), Luigi Monica (Italian National Institute for Insurance against Accidents at Work (INAIL)) and Michael Wichtl (Austrian Ergonomics Society (ÖAE)).

Abstract. The concept of work system design can be used to analyse, design, and evaluate links between human factors and ergonomics (HFE) and machine and system safety. To support safety and health in machinery design, HFE findings related to the design of machines and technical systems and human-system interfaces have been collected and compiled for presentation to designers of machines and systems as well as occupational safety and health experts. The concept of work system design in HFE structures the content of and the relationships between relevant system components, i.e., work task, organisation, place, equipment, and environment. Concepts and content are briefly presented, design recommendations are illustrated, and further reading is referred to by relevant standards and scientific literature.

Work equipment design issues in HFE have recently been added to the presentation. With the digital transformation, the focus of in the design of human-system interaction is rather focussing on human information processing and related design principles for the task, the interaction, and the information interfaces. Therefore, detailed information is presented on human information processing and design principles referring to the design of classical displays and control actuators as well as for digitalised interaction interfaces. Some examples will be used to illustrate proven design principles and discuss limitations and new ways of integrating further design requirements and solutions to improve machine and system safety. In addition, the changeover from the current (Machinery Directive 2006/42/EC) to the future (Regulation (EU) 2023/1230 on machinery) Machinery Regulation, being effective 2027 onwards, will be addressed and the role and urgent need for updating harmonised standards on HFE in machine and system safety will be discussed.

Keywords: Human Information Processing, Work Equipment Design, Display Design Principles, Control Actuator Design Principles, Human Factors and Ergonomics, Machine and System Safety, Work System Design

How can functional AI be safely integrated into a machine?

Michaël Sarrey (INRS).

Abstract. Integrating machine-learning (ML) into automation brings new capabilities and new constraints to machines. In 2021, the SIAS conference paper entitled "AI algorithms within machinery: Safety issues" presented the specific features of LA machines. From these specificities and thanks to new studies and a relevant case, this paper aims to guide machine designers, integrators and end-users of these machines.

The processes for designing and using learned automation will be developed as follows:

i. needs analysis (how to be sure that learned automation is the good solution to solve the problem),

ii. proof of concept and choice of the technical solution (how to test and validate the automation system before building it),

iii. phase of the machine's life cycle related to the creation of a data bank (how to safely create a machine learning data bank),

iv. the "learning" operating mode (how to implement a learning function in the machine as part of a programming operation),

v. performance analysis and validation (how to measure and analyze the algorithm performance),

vi. maintenance (how to check the LA system),

vii. technical documentation (how to explain the use of the LA system to operators and maintenance personnel).

An online quality control application of organic products (such as fruit or wooden plank type) will serve as an example for the design and safety integration process; advices and best practices for maintenance and operation will also be provided. Furthermore, this paper emphasizes the study and the realization of the graphical user interface (with learned automation). This interface is a key factor in the success of safety integration.

The whole approach is oriented towards the prevention of occupational risks related to machines. In other words, what are the safety impacts of learned automation compared with conventional automation?

Nowadays, learning techniques do not directly integrate safety functions, but they can have an indirect impact on safety.

Keywords: artificial intelligence, machine, safe design

Preliminary Title: Supervisor-Machine Shared Decision-Making for Runtime Hazard Mitigation in Highly Automated Machinery

Marea de Koning (Tampere University), Tyrone Machado (Tampere University), Reza Ghabcheloo (Tampere University) and Tatiana Minav (Tampere University).

Abstract. The European Union (EU) dominates the machinery manufacturing sector with an impressive annual turnover of €740 billion [1]. Its commitment to ensuring high levels of protection and safety for workers and citizens is evident through the EC declaration of conformity on machinery. Recognizing the evolving risks in off-road machinery, the EU has taken substantial steps by introducing Machinery Regulation 2023/1230 [2]. Effective from January 20th, 2027, this new regulation demonstrates a proactive response to current legislative limitations, aiming to enhance safety in the European off-road machinery industry, particularly as automation increases [2]. However, anticipating all potential failure scenarios for highly automated machinery is practically impossible, posing new safety compliance challenges and necessitating a shift in standardized safety practices. While the previous focus was on ensuring the absence of failure modes through verified and validated design methods, the current emphasis lies in ensuring the capacity to safely handle unforeseen events [3] .

Legislative safety requirements for highly automated machinery acknowledge this challenge and advocate for robust risk management systems, often incorporating a human-in-the-loop safety option [2],[4]. In such systems, a human supervisor is expected to intervene when necessary to ensure a safe state. Yet, in highly automated machinery where the operator's role has shifted to a supervisory capacity, relying on a human to promptly intervene during runtime becomes impractical. There can be measurable costs to human performance when automation is used, including the onset of boredom, complacency, confusion on control goals/responsibilities, reaching the limitations of a supervisor’s cognitive capacities, loss of situational awareness and automation bias [5]. These factors diminish the reliability of human supervisors' ability to intervene and bring the machine into a safe state. Therefore, this significantly increases the risks of hazardous situations when highly automated machinery is placed within the market.

Off-road machinery manufacturers shoulder a pivotal responsibility and liability in ensuring the market placement of machinery compliant with safety legislation. Particularly in the context of highly automated machinery, establishing requirements for mode stability between humans and machines becomes imperative. This means defining the capacity and responsibilities of both the machine and the supervisor to effectively mitigate hazards as these emerge during operation. The focus on mode stability requires a closer look at the machine's capacity off (pro-)active risk mitigation, addressing critical aspects that extend beyond the current scope of machine safety standards. One wonders what is required for machinery and what can reasonably be expected from supervisors to adequately respond to operational hazards, and when can we argue that we have exercised sufficient engineering rigor to be compliant with machine safety legislation?

In the face of evolving automation, it is essential to bridge these gaps to ensure the seamless integration of highly automated machinery while maintaining a high level of safety and efficiency. This article analyses discussions within the domain of safety in highly automated machinery, proposes a taxonomy of various degrees of shared decision-making, allocates responsibilities, and establishes minimum safety requirements for situational awareness and monitoring human engagement. Our contribution aims to guide future standardization efforts for safe highly automated off-road machinery and support manufacturers in their machine safety compliance efforts.

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Keywords: Automation, Machinery, Safety, AI proposal, Machinery regulation, Risk management, Decision-making, Runtime Hazard Mitigation

EU safety regulations and standards for autonomous mobile machinery

Timo Malm (VTT), Risto Tiusanen (VTT) and Josepha Berger (VTT).

Abstract. There are a lot of expectations to autonomous mobile machines. They can provide innovative way to increase productivity. One of the main concerns in autonomous systems is safety, especially, when there are both autonomous and manual machines and persons in the same autonomous area.

This paper aims to show an overview of requirements and guidelines, which are presented to autonomous mobile machines and give some ideas how the machines and machinery systems can operate safely. The focus is on machines, which operate in difficult environment, where the capability of sensors for object detection is limited. Regulations and standards give both mandatory and voluntary guidelines to make safe autonomous mobile machine systems. In all cases the systems must be adequately safe. There are many kinds of autonomous systems and it is difficult to fit the rules in similar way to all of them. There are new requirements and they will affect many autonomous mobile machines.

New Machinery Regulation (EU) 2023/1230 of June 2023 gives first time in legislation requirements for autonomous mobile machines. According to the Machinery Regulation the definition for 'Autonomous mobile machinery' is: mobile machinery which has an autonomous mode, in which all the essential safety functions of the mobile machinery are ensured in its travel and working operations area without permanent interaction of an operator. Also supervisory function for supervising autonomous mobile machines remotely have been defined. If relevant, it is obligatory and its purpose is to stop, start, or move the machine to safe state or position. It is not meant for other remote control operations and when it is applied, protective devices are operational and the operator must be able to see directly or indirectly the machine and the working area. This requirement looks quite strict and it requires more guidance.

According to the Machine Regulation autonomous mobile machinery must have either a peripheral protection system comprising guards (and) or protective devices or they must be equipped with devices intended to detect any human, or any other obstacle in its vicinity, where those obstacles could give rise to a risk to the health and safety. This means that protective devices are obligatory either onboard the autonomous mobile machine or in the infra. Apparently, standards are going to specify the requirement in more detailed level.

The machinery regulation has also specific requirements to for autonomous mobile machinery failure in the steering system. The failure must not have an impact on the safety of the machinery. This is new requirement in legislation and specific for steering system. Some more detailed requirements can be found for earth-moving machinery (ISO 5010:2019). It is obvious that steering must operate correctly to move autonomous mobile machine to right direction. Is it enough to stop a machine with failed steering or are there other means. In manual machines the driver can detect the malfunction and do necessary actions intuitively. Also other failures need to be considered, but the requirements are in standards, not in legislation.

Autonomous mobile machines or highly automated machines are mentioned in several safety standards, but they are specific for domains.

- Standard ISO 17757:2019 "Earth-moving machinery and mining—Autonomous and semi-autonomous machine system safety". The standard describes, among others, autonomous mobile machine system, which can include a fleet of machines.

- Standard ISO 3691-4 "Industrial trucks—Safety requirements and verification — Part 4: Driverless industrial trucks and their systems". The standard describes, among others, onboard safety functions and devices, which suit best for indoors use.

- Standard "ISO 18497:2018. Agricultural machinery and tractors — Safety of highly automated agricultural machines". The standard describes, among others, the onboard protective functions and devices.

The current situation with autonomous mobile machine requirements is that in upper level the Machine Regulation gives strict requirements, but standards need to specify more detailed the intentions. In outdoors applications the sensors can be in hostile environment and detection beams of sensors may wobble as the machine drives forward on a bumpy terrain. It is difficult to have common requirements for all autonomous mobile machines. The requirements need to be domain specific now, since there are no multipurpose solutions for autonomous operations.

This review of EU safety regulations and standards for autonomous mobile machinery and the study of their implications have been conducted in VTT as a part of the research project 'Shared Situational Awareness for Optimized and Safe Mixed Fleets' (MixedFleet) , which is mainly funded by Business Finland.

Keywords: Mobile machinery, autonomous, safety of machinery, regulations

Virhe. Viitteen lähdettä ei löytynyt.

Identification of safety risks in mixed traffic concepts in industrial sites

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Abstract. Despite the progress in automated driving technology, fully automated heavy industrial vehicles still need to be separated from human workforce. Different operating environments and work processes require different solutions to ensure safe operation of the autonomous or semi-autonomous machinery systems. In industrial logistic systems an interesting and challenging vision is to enable automated machinery, manual machines, and manual workers to operate and collaborate in the same operating area. This is called a 'mixed traffic' or 'mixed mode' operation.

From safety point of view, there are certain facts that support the development of these concepts. Industrial production sites like pulp & sawmills, container terminals, or mines are semi-restricted and more structured than public roads and open work sites and operating environments. Personnel and subcontractors at industrial sites are professionals and aware of the operational hazards and risks, they follow the safety instructions and know what to do in emergencies. And on the other hand, modern safety systems are based on advanced software solutions and

safety functions can today use situational awareness information from several interacting systems. For 'mixed traffic' operation concepts, it is crucial to develop new principles and criteria for converting situational and site

information into a dynamic "risk awareness" component, which can then be integrated into the situational awareness system of automated operation.

According to the general systems engineering approach, risk management decisions in the system-development process are made systematically as the system development proceeds. In practice, the design decisions to reduce the safety and availability risks are based on comparison of alternative solutions at different layers of protection and prediction. The systematic and clearly phased safety engineering approach and risk assessment process supports the development of machine autonomy when selecting operating concepts and technological solutions. New methods and tools are needed when designing interactions between autonomous machines and human operators in safety critical decision-making situations. Advanced safety engineering procedures need to be in place to not only identify and control new safety risks, but also to document and communicate safety-related aspects between all relevant stakeholders.

The traditional system safety methods like Preliminary Hazard Analysis (PHA) and Operating Hazard Analysis (OHA) have been successfully applied in several automated machinery applications. They continue to have an important meaning when effectively use in the system safety engineering process, but these methods do not cover or consider autonomy aspects especially safety critical interactions between systems in different autonomy level. The new challenge is that machine's autonomous behaviour cannot be fully predetermined because the key element in machine autonomy is adaptability to dynamically changing environment based on the perception of the available information. The System-Theoretic Process Analysis method STPA brings in new views for the analysis of autonomy aspects by supporting the identification of unsafe control actions. STPA method includes the modelling of the hierarchical control structure of the machinery system and complements the perspectives of traditional system safety methods. The method provides a formal presentation to connect losses - system level hazards - unsafe control actions and risk scenarios.

The purpose of this study is to find out how the STPA method supports and complements the PHA method to identify safety risks and potential problems related to autonomy and the interaction of systems in different autonomy level. In this study the approach for hazard identification and risk assessment is a combination of

Preliminary Hazard Analysis (PHA) method and System Theoretic Process Analysis (STPA) method used in early conceptual phase of the system design process. Other research questions in this study are: How to formulate safety goals and system level safety requirements to support system design and system verification and

validation activities, and what information is needed to be able to set safety goals for mixed autonomy operations and system safety constraints for STPA? In this study we have two industrial case systems. The first one is an autonomous transportation system developed for sawlog transportation in a sawmill environment. The other system includes automated container handling operations and autonomous container transportation in an intermodal terminal environment.

The results and our experience using the PHA and STPA methods confirm earlier results that STPA complements and in a way continues the safety analysis made applying PHA. First, in this study we identified using PHA the most important autonomy related hazards and hazardous situations related to transportation and material handling operations and assessed the significance of the safety risks caused by them. Secondly, using STPA and starting from the system level hazards we identify possible unsafe control actions and to specify loss scenarios related to them. In the PHA, hazards and dangerous situations are identified at a general level without going into more detail about operating procedures, system usage situations or control actions. STPA method then specifies control actions, identifies unsafe control actions that must be prevented. After potential unsafe behavior is identified, then the specific design features can be created, and safeguards added, or the adequacy of existing design decisions and safeguards can be determined. The concrete results of the work in terms of the project's case systems are proposals for risk reduction options and requirements for safety measures to ensure safe autonomous and automated operations.

This study is part of the EU and Business Finland funded research project ‘Artificial Intelligence using Quantum measured Information for real-time distributed systems at the edge’ (A-IQ Ready). The safety research in the project aims for improving safety and productivity of automated vehicle operations outdoors in co-existence with human workers. The main target of the safety research is to develop data fusion concepts and risk conscious situational awareness for autonomous driving and load handling.

Keywords: autonomous, work machine, conceptual design, hazard identification, risk assessment

Towards “Positive Safety” -New trend in occupational safety and health-

Masao Mukaidono (The Institute of Global Safety Promotion (IGSAP)), Toshiyuki Kajiya (The Institute of Global Safety Promotion (IGSAP)) and Toshihiro Fujita (The Institute of Global Safety Promotion (IGSAP)).

Abstract. Foreword

Conventional activities in occupational safety and health have mostly focused on reducing risks, such injury, disease, and mental disorders caused by work. In other words, activities were mainly intended to raise the status of workers from minus to zero. From now on, we should also focus on proactive approaches in the positive domain, i.e., to bring the status of workers from zero to plus. Acting on raising workers’ safety, health, and well-being from zero to plus in positive domain will enable workers to engage in their work with the sense of anshin (peace of mind), health, vitality, and also a sense of accomplishment.

Positive Safety

No one would argue that the ultimate goal for working people is to work healthy, and happy in a safety environment. Safety activities, accordingly, should not only focus on activities in the negative domain from minus to zero, but also on activities in the positive domain from zero to plus, such as seeking more health, happiness, anshin, comfort, and a sense of accomplishment. This is the purpose of the "positive safety" presented here.

Positive safety in the field of occupational safety aims not only to participate in activities within the conventional negative safety domain, where risks are minimized to acceptable levels, but also to broaden its scope to the positive domain. This includes embracing acceptable risks, liberating oneself from potential hazards, and actively, freely, optimistically, and comfortably pursuing advantages in the workplace. This goes beyond the concept of safety alone. Similarly, concerning health, the goal is to transition from activities in the negative domain, which concentrate on eliminating work-related illnesses (physical diseases and conditions), to the positive domain where individuals are physically, mentally, and socially well, actively participating in activities with energy and enthusiasm. Furthermore, in the realm of mental and emotional well-being, the aim is to expand activities from the negative domain, where there are no mental disorders or issues due to work, to the positive domain where individuals actively work with enthusiasm, seeking fulfillment, purpose, and happiness in their lives.

In this way, positive safety is not just about conventional activities that involve identifying hazards and reducing their risks but also focuses on safety activities that look at the positive aspects of working with positivity, cheerfulness, and a sense of purpose. Therefore, in positive safety, the concept of safety extends beyond the narrow domain of physical "safety." It expands into the broader areas of "health" and the mental domain (well-being), involving a sense of fulfillment and purpose in work, targeting "broad safety," which refers to safety, health, and well-being. The direction and targets align with what has already been demonstrated in Vision Zero initiatives.

Well-being Tech

As evident from the above definition, positive safety involves not only things (machinery and equipment) and organizations (systems and structures) but also the human mind and spirit. To technologically achieve positive safety, the concept of collaborative safety, where machines, organizations, environments, and humans work together to ensure safety, is implemented through recent technologies such as ICT and AI. Safety2.0 technology plays a crucial role in this. It enables occupational safety and health activities that consider the psychological aspects of human beings, extending beyond the field, such as manufacturing or construction scenes, and into the entire office environment. In this way, Well-being Tech refers to technology aimed at ensuring the safety and health of individuals, promoting a sense of anshin, and fostering fulfillment. This paper provides an overview of Wellbeing Tech, currently being implemented in practice.

Positive Safety and Management

Traditional occupational safety and health activities, primarily focused on the negative outcomes caused by work, often lead to perceiving safety costs as expenses. There is a tendency to cut safety costs whenever there is even slight progress in safety. On the other hand, positive activities in occupational safety and health activate both safety and productivity, enhancing the sense of happiness for the workers. Through these initiatives, the company's activities contribute to societal well-being. In this scenario, from a business management perspective, there is a shift in considering safety-related costs not as expenses but as investments. Consequently, occupational safety and health are expected to be actively incorporated into the cycle of management initiatives as a crucial business issue.

Afterword

Traditional occupational safety and health activities have primarily focused on industries such as manufacturing, where machines and humans can be somewhat isolated, with the aim of achieving zero occurrence of serious accidents. Future occupational safety and health activities need to expand beyond these manufacturing industries to include a wide range of sectors, including service industries, where machines and humans work together in the same workplace. At that time, it is essential to not only ensure a physically safe environment and maintain health but also strive for workplaces that value human hearts, including satisfaction and a sense of purpose. An important perspective here is that, along with the transition from negative to zero, adopting a positive safety approach of progressing from zero to positive becomes crucial. It is believed that now is the time to shift the mindset of future occupational safety and health activities towards the direction of positive safety.

Keywords: Positive Safety, Collaborative Safety, Well-being Tech

Holistic Approach to build the Global Platform of Collaborative Safety based on the Wellbeing Technology

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Abstract. Human-centered smart society is currently a global concern aiming at the universal and eternal concept of peoples “safety, health and wellbeing”. When we look at the manufacturing industry sector that has been contributing largely the Japanese national economy, the reduction and limitation of workforce has recently become serious problem due to aged society, and the industry is making every effort to maintain high efficiency and productivity by introducing emerging technologies such as robotics and ICTs in place of workers. On the other hand, the current safety measures with reference to the international machine safety standards published by ISO and IEC focus mainly on the hardware-oriented physical safety without consideration of human’s psychological aspects leading to “ANSHIN” that is Japanese expression and is generally understood as the feeling of freedom from threat against possible hazard under the working environment of human-machine coexistence.

“Collaborative Safety” is the new concept that the preventive measures to the potential safety hazards caused by the human access to or from the moving machine and guide to safe situation by way of real time exchange of the risk related information among human, machine, and their working environment, utilizing the advanced ICT such as AI and IoT. In other words, collaborative safety is to establish “friendship” relationship between human and machines so that human can gain the feeling of ANSHIN. This concept is understood as the core element of “Wellbeing Technology” that is the safety technology providing the workers with not only safety and health but also wellbeing as an ultimate goal.

In order to build the collaborative safety platform at workplace, technical measures of system level are essential but at the same time personnel competence to justify the correct installations/integrations and operations, their overall management to maintain sustainably the system operations, and finally their common rule making by way of international standardizations of both technical standard and its conformity assessment to be used as a tool/reference for overall industries on a global basis to contribute UN SDGs, especially Goal 3 and 8. We call this idea as holistic approach to build the collaborative safety platform and we IGSAP is taking a leadership to develop our private standard and conformity assessment program, and in parallel, to implement them on-site in manufacturing, civil engineering and construction industry sectors which are expecting to minimize any hazardous event for their employees and to work with positive motivations without feeling any stress and threat of safety hazard by employing advanced safety technology.

The paper outlines the progress of international standardization of our holistic approach to build the global platform of collaborative safety in the organizations since we started some years ago, in terms of the following elements;

1) Safety 2.0 technology

Safety 2.0 is our unique term of technical aspects in collaborative safety and Safety 2.0 standard developed by IGSAP has been improved in accordance with our on-site experiences of Safety2.0 conformity assessment activities to implement the standard. Especially our focal points for the improvement are, whether the system level risk assessment covers sufficiently, and whether efficiency and productivity are still secured by the safety measures introduced. The principle of the standard is proposed to the IEC ACOS (Advisory Committee on Safety) to develop IEC Guide on collaborative safety.

2) Personnel competence

By the leadership of Japan, new conformity assessment program called CoPC (Certification of Personnel Competence) program was introduced in IECEE dealing the CB Scheme, with reference to the Japanese Safety Assessor program on machine safety. This is currently the initial stage and planned to be expanded to the CoPC program on collaborative safety in the near future.

3) Management system

We are in process of consultation with the parties concerned how the collaborative safety management system is integrated in the relevant part of the existing ISO45001 OHSMS to include how to measure and verify the “wellbeing” gained by the employees as a result of the introduction of collaborative safety in the organizations.

4) Promotion and partnership

It is crucially important for the international standardization activities to make friends as many as possible who agree and support our proposals. For this purpose IGSAP is actively involved in a number of national and international events to promote collaborative safety and establish the partnership with the relevant national and international organizations.

Keywords: Collaborative Safety, Wellbeing Technology, Holistic Approach, International Standardization, Anshin

Study on dangerous and safe errors of human towards realizing collaborative safety - Examine of workability using safety/danger signals on tablet

Shoken Shimizu (National Institute of Occupational Safety and Health (JNIOSH))

Abstract. In many manufacturing industries today, "cooperative work" is performed by man and machine, and new safety measures are required under this situation. Current machine safety standards allow workers to enter the working area of machines, but do not allow contact between workers and machines. Conventional protection devices can detect the approach of a worker and stop the machine, and adjust the speed according to the worker's ability, but in machine safety, worker behavior is treated as a black box that cannot be predicted. Therefore, it has not been assumed that the worker's attentiveness is utilized so far. However, it is necessary to examine how information from the machine side can be presented to the worker to obtain the intended action in order to make collaborative work more efficient. In this study, we used a tablet to examine how worker behavior changes depending on the information presented by visual stimulation from the machine side. First, we classified the erroneous behavior of workers. If the worker continues to work without noticing a problem that has occurred in the machine during work, a hazard will occur (dangerous error). If you notice an obstacle and press the emergency stop button, it will be avoided. Additionally, if you press the emergency stop button even though no fault has occurred, you will be on the safe side. A safe error means that although it is an error that hinders work efficiency, it does not pose a danger to the worker. Experiments were conducted with 8 university students and 36 manufacturing employees, and the safety requirements necessary for collaborative work were clarified. We set four conditions: 1) no visual stimulation, 2) presentation of only safety signals, 3) presentation of only danger signals, and 4) presentation of both safety and danger signals, and calculated the dangerous error rate under each condition. The results for 40 subjects showed a significant difference between 1) no visual stimulation and 4) conditions in which both a safety signal and a danger signal were presented, demonstrating the effectiveness of safety signals and danger signals in preventing dangerous errors. In addition, it was revealed that the risky error rate increased in the pattern in which 2) only safe stimuli were presented compared to 1) without visual stimuli. Next, we conducted an analysis separately for university students and manufacturing employees. For university students, significant differences were observed only under conditions of 1) no visual stimulation and 4) both safety and danger signals. Among manufacturing employees, 1) compared to no visual stimulation, 4) risky errors were significantly lower when both safety and danger signals were presented, similar to university students; however, 2) safety Signal alone resulted in more dangerous side errors than visual stimulation. The results showed that 1) the pattern in which the risky error rate decreased the most compared to the pattern without visual stimulation was 4) the pattern in which both a safety signal and a danger signal were presented. In addition, it was revealed that the risky error rate increased in patterns in which only safe stimuli were presented (2) compared to 1) without visual stimuli. Although these results support the idea that safety increases when conventional danger signals and safety signals are used. On the other hand, a quite new possivility to signal effect is suggested that unsafe behavior increases when safety signals are used alone. It was also suggested that there are differences in signal sensitivity between university students and manufacturing employees, which might be exposure history to safety/dengerous signals. In the future, it seems necessary to conduct more detailed verification experiments with the same number of subjects.

Keywords: dangerous error, safe error, manufacturing, occupational safety

A systematic activity for safety education and awareness at a rental company of temporary equipment to workers at construction sites

Yuka Koremura (Koremura Giken, Col. Ltd ballast Dept.), Shoken Shimizu (1 Safety and ANSHIN Technical Research Center (SATEC), GOP corporation) and Rieko Hojo (4 Nagaoka University of Technology)

Abstract. A company that rents portable workbenches and other equipment is promoting safety education and awareness for workers at construction sites. The company's awareness promotion staff named "Team SG Cosmos'' who have been trained in acting go to construction sites and explain the safe use of portable work tables and other precautions in the style of short dramas. The short drama also shows the importance of pointing and calling and talking among workers, and sometimes the workers jump in and participate in the short drama. Though Japanese regulations do not specifically require such activity, the activity based on on-site conditions are quite popular among workers at many construction sites. The "safety awareness promotion activities" carried out by SG Cosmos members on-site are based on the 3-step method (1) intrinsically safe design measures, 2) safety protection, and 3) usage information, which is a method of risk reduction measures implemented by manufacturers. Among these, the purpose is to share the third step, which is the "usage information (residual risk information)." Normally, risk reduction measures in this step involve one-way communication of information such as "manuals", "precautionary notes", "warning marks", and "alarms". However, the activities carried out by SG Cosmos are different from such current one and mainly based on participatory and experiential information sharing with workers, and are characterized by mutual information sharing. Activities like SG Cosmos are rarely seen not only at construction sites but also in other workplaces. The name “Safety Awareness Promotion Activities” carried out by the SG Cosmos means that the purpose of this activity is not simply an "awareness campaign'' in which SG Cosmos provides information on residual risks, but rather a focus on workers' spontaneous participation on the activities. This indicates that the activities are “activities aimed at the self-development of workers,'' with the purpose of obtaining benefits for workers themselves. In commonly held safety courses, it is common to check the level of understanding of the course content through tests and questionnaires conducted after the course. However, the important thing is that the purpose of the course will be achieved if the participants understand the content, are willing to take the prescribed safe actions, and actually take those actions. Therefore, the Safety and Security Technology Research Centre (SATEC) in the workbench rental company has examined whether workers who have attended the safety awareness promotion activities conducted by SG Cosmos understand the content and are willing to take appropriate actions using the following two questionnaires about two types of well-beings. "Well-being" refers to a state of continuously good (being well), and refers to continued happiness, health, and welfare in a broad sense. In particular, subjective well-being (hereinafter referred to as SWB), which refers to safety and comfortability state of human beings, is an index that evaluates one's job satisfaction and feelings of safety and security, and is composed of five questions. On the other hand, psychological well-being (hereinafter referred to as PWB) is an index that evaluates conditions such as relationships with others, independence, and the self-acceptance etc. It consists of 18 question items. The experiments were conducted with 2 members of the SG Cosmos and 6 workers at a construction site. The questionnaires were conducted before and after a safety awareness promotion activity by SG Cosmos, and held during a part of the work lunch break with permission. The subjective well-being evaluation results before and after the safety awareness promotion activities showed that both on-site workers and members of SG Cosmos had better points in the subjective well-being after the activities than that of before. Also, it was clarified that they felt safer and more secure after the activity. These show that the workers were satisfied with the content of the activities carried out by SG Cosmos and understood that implementing the content would provide safety and a sense of security. Furthermore, the activities carried out by SG Cosmos indicate that they felt that ensuring safety gave them a sense of security. Next, the evaluation results of psychological well-being before and after the safety awareness promotion activities show that workers are more satisfied with the efficient use of the opportunity to participate in the activities (before taking a lunch break before attending the activities). Although the attendees may have felt dissatisfied with using their precious time to attend the course, their feelings of satisfaction changed after the course was completed.) Members of the SG Cosmos also showed that they felt an increased sense of satisfaction from completing the project after completing activity. I believe that the ideal way to conduct a course is to have a win-win relationship between the course provider and the participants.

Keywords: safety education and awareness, construction, workbench

Machine safety with collaborative press brake application

Juho Pirttilahti (Seinäjoki University of Applied Sciences) and Juha Hirvonen (Seinäjoki University of Applied Sciences)

Abstract. As generations age, finding skilled labor for the metalworking industry is becoming increasingly difficult. The problem is compounded by the fact that younger generations are less interested in the physical work of the industry and in learning the traditional skills required of production workers. In addition, the increasing complexity of products and quality requirements, as well as the general shortening of working lives and increased competition, particularly in SMEs, pose significant challenges for the training and qualification of staff.

Robotics has been present in the metalworking industry for decades and its role has increased with technological progress. Robotic applications in the metal sector have mainly focused on welding and related processes and machine service. In recent years, the integration of collaborative robotics, known for its versatility and safety, has increased in many applications and uses as technology has developed. Applications have also seen an increase in the integration of collaborative robotics to work with older production machines.

In this paper, we present a collaborative press brake application that uses a collaborative robot (also known as a cobot) to perform a series of operations on a series of sheet metal parts. The benefits of automated machine operation mirror those of automating production tasks in general, improving efficiency and accuracy and freeing up workers to perform other tasks while the series is in production. This application is equipped with a safety scanner and ABB's SafeMove function to meet stringent machine safety standards. The paper discusses the harmonized machine safety standards and risk assessment required to evaluate the application and presents the process and results of the risk assessment of this application. The ISO 12100 standard is used as a reference framework for risk assessment and mitigation. The article also compares a real application using a collaborative robot with a simulated application using an industrial robot in the same machine maintenance task. The aim is to compare the safety characteristics required for a collaborative robot application and a traditional industrial robot application.

The results of the article show the differences between a real collaborative robot application and a simulated industrial robot application. The main conclusions are that the use of a collaborative robot makes material flow management more flexible and application programming and minor modifications easier. In addition, the use of a collaborative robot saves expensive floor space in production. SMEs have also shown interest in integrating a robot into an older production machine already in use as a cost-effective way to modernize and improve productivity. In practice, however, a collaborative robot cannot usually run a series as fast as an industrial robot because it is not isolated by fences, and the high speeds of an unisolated robot are usually dangerous from a machine safety point of view. In addition, an industrial robot has a better load-bearing capacity than a collaborative robot. The application attracted the interest of SMEs because of its production efficiency and staff involvement. In addition, the mobile collaborative robot station used in the application attracted the attention of SMEs because of its versatility. However, current standards require the station to be stationary during the risk assessment process and the risk assessment of a collaborative robot is generally a more demanding process than for a traditional fenced industrial robot.

Keywords: cobot, press brake, metal manufacturing industry

Relation between safety and happiness for worker at work - Introduction of case studies from quantitatively measure and visualize well-being to connect to “KAIZEN”

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Abstract. Up until now, we have always aimed to reduce risks and eliminate accidents as the goals of occupational safety. By conducting risk assessments of machinery and work and implementing “intrinsically safe design” and “safety protection and additional protection measures”, we have created an environment for safe work and strived to reduce risks as close to zero as possible. There is no doubt that these efforts to date continue to be important, but workers, assigned risk reductions, tended to be focused on and pointed out where were not sufficient. Although it was necessary, workers tended to be attitude passive rather than proactive against safety promotion and risk reduction activities.

The times are changing, as recent global trends reflected in SDGs and other initiatives are also pursuing “work satisfaction”, or well-being, for workers. The well-being is defined in the preamble of the WHO Charter: “Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”. Translating this definition to workplace, it becomes a state in which “employees are satisfied physically, mentally, and socially in the workplace”. In recent years, emphasis has been placed on the idea that creating such an environment should make the workplace more comfortable, strengthen organizational strength, and increase performance and motivation. In fact, Goal 8 of the SDGs sets out “Decent Work and Economic Growth”, which aims to protect the environment, promote sustainable economic growth, and ensure that all people have meaningful and well-paid work. By having workers more proactively involved in safety, it will also lead to activities where they can create safety themselves. In other words, the movement for workplace well-being stems from the current need for workplaces to not only be safe and secure, but also to satisfy the motivation to work, such as having a sense of purpose in life, fulfillment and job satisfaction.

C. Ryff (1989), an American well-being researcher, says, "At a more general level, the field of psychology has, since its inception, been more concerned with human misfortune and suffering than with the causes and effects of positive functioning". Now there is a growing interest in the study of psychological well-being, recognizing that it has received far more attention. Psychological well-being is nothing but well-being, which is defined as "sustainable happiness". Similarly, a new concept of "positive safety" has been born in Japan. This can be said to be a new direction for occupational safety, which aims not only to avoid risks but also to transform the workplace into a safe, comfortable, and rewarding place. Based on this philosophy, we started to measure safe/unsafe behavior of worker quantitatively and objectively and to analyze safety and well-being of workers, and if necessary, make improvements to the workplace to improve the workplace environment. In other words, we are now attempting "optimization" at work.

We hypothesize that there are two types of workplace well-being. In other words, the happiness that comes from being given a "safe and secure workplace", and the happiness that comes from finding "purpose in life", "challenge" and "job satisfaction". When you have a "safe and secure workplace", you feel a general feeling of well-being that we associate when we hear the word "happiness". It refers to the "achievement of pleasure" in which the greater the intensity and frequency of emotions, the greater the sense of happiness. This is called "subjective well-being". It can be said that previous efforts to reduce the risk of occupational accidents (defined as a function of the "severity and frequency of harm") have contributed to this improvement in subjective well-being. Furthermore, the "sense of accomplishment" that you feel when you make the most of your abilities and realize your personal goals and objectives is another type of well-being called "psychological well-being". We believe that establishing a work environment in which workers can feel more comfortable and self-actualized while working constitutes psychological well-being. In the future, as advocated by the SDGs, it is the responsibility of corporate management to take measures and strategies to enhance these two types of well-being. In addition, a means of evaluating them is required.

In this talk, I quantify and "visualize" these two types of well-being in the workplace, and propose an "optimization" method to improve the visualized well-being.

In our project, we will construct a measure of well-being specific to workers in the field, based on the measures of subjective well-being and psychological well-being established by Diener (1984) and Ryff (1989), respectively. That is the final purpose.

In this project, we will introduce data from 92 people who responded to an online questionnaire from September 4, 2023 to December 26, 2023. A radar chart was created based on a total of 7 items: The subjective WB scale developed by Diener and the six subscales of psychological WB proposed by Ryff. Six subscales are: 1) Personal growth, 2) Purpose in life, 3) Autonomy, 4） Environmental mastery (controlling the environment), 5) self-acceptance, and 6) positive relationships with others. Radar charts of various shapes were observed for various industries, and it became clear that there are industry-specific differences in WB. In the future, we plan to use behavioral analysis interventions to optimize the workplace.

Keywords: Well-being, Occupational safety, KAIZEN, Behaviour Analysis

Survey for reduce the burden on snow removal work

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Abstract. In Japan, elderly society is progressed and the number of workers in construction industry have been decreased likewise in many other industries. As snow fall area are occupied about 1/3 in Japan, the situation of lack of workforce especially serious in these snowy regions. In addition, many kinds of special skills are required for operators of snow removal because of a characteristic of Japan's road environment such as existing many narrow roads and obstacles.

In order to identify current problems, a survey was conducted on snow removal operations at Nagaoka University of Technology. The reason for targeting snow removal operations at Nagaoka University of Technology was that the amount of snowfall was expected to be large, and modeling of the work situation was expected to be easy. A drive recorder was installed in the vehicle to film the operator of the rotary snowplow, and several days of snow removal work during snowfall were recorded. In addition, we interviewed the operators about problems, requests, and key points of operation. The work data for analysis was the recorded data from 6:50 to 7:20 on January 8.

This hearing result said rotary snow removal machine operator worry about damage to road ancillary equipment and to occur snow jam of shooter. If snow jam of shooter occurs, the rotary snow removal machine operator must get out of the cockpit and use a shovel and his hands to remove the snow jam from the shooter. It was commented when that ride on and off and removal of snow jam was burden on snow removal worker. The snow removal crew commented that getting in and out of those snow removal machine and removing snow jams was burdensome.

The result of the rotary snow plow operator motion was record by the drive recorder shows 4 sections operator’s motions of snow removal work.

The first section is Moving and Previewing. While moving from one snow removal area to the next, the operator looks at snowfall conditions and determines the need for snow removal operations. In this survey Moving and Previewing section accounted for 57% of snow removal work, making it the most time-consuming part of the snow removal process.

The second section is Remove snow jam in the shooter of the rotary snowplow. This section is accounted for 31% of snow removal work in this survey. The shooter is a cylindrical structure that controls the direction in which snow is thrown. In addition, actions that supported the hearing comments included getting out of the driver's seat of the rotary snowplow to remove snow, as well as tapping the ground with the auger case to remove snow jams while in the driver's seat.

The third section is snow removal work. The snow removal operations are conducted to move snow that obstructs traffic on the university campus to other locations. This is essentially the expected use of rotary snowplows, and this task should account for a large percentage of the total work, but in this survey, it only accounted for 6% of the total work time.

The fourth section is parking. This section is park the rotary snowplow to carport. This task accounted for 4% of the total worktime.

In this survey, it was found that a disproportionately large amount of the work done by rotary snowplow operators involved removing snow jam in the shooter of the rotary snowplow, compared to the time spent snow removal work. Based on the results of the hearings and video analysis, we guess that these events are caused by the aging of the rotary snowplow trucks and the snow being moistened by the snow-melting pipe, which makes it easier for snow to stick to the surface of the shooter. In the future, as a method to reduce the occurrence of snow jam, painting the shooter to make it more difficult for snow to stick to it and providing information to operators on the location of snow-melting pipes will be consider, and their effectiveness will be verified.

Keywords: snow removal, snow removal machinery, automation, reduce burden, construction safety

Proposal of Risk Assessment Method of Collaborative Safety to Improve Safety and Productivity Simultaneously in Manufacturing Field

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Abstract. In the manufacturing field, there are many needs for equipment that can be changed flexibly to accommodate variable production and for robots and other machines to work in place of humans to compensate for labor shortages due to a shrinking workforce. However, even though technology is advancing rapidly, it is not possible to replace all tasks with machines and completely automate them in a single step. For this reason, there has been a rapid increase in the use of collaborative robots and AGV/AMR, which do not require the installation of safety fences or guards, as applications where humans and machines can coexist and sometimes work together.

Traditionally, machine/machine system protection measures, i.e. machinery safety based on ISO 12100, have been applied to ensure the safe use of machines. Machinery safety is based on the principle of isolation and stop, and requires a high reliability level for safety functions based on the assumption that "people err in 100% of the cases".

Therefore, when applying machinery safety to coexistence/collaboration applications, the production engineers have often reported there are problems such as "once the machine stops, it takes time to recover," "frequent stoppages reduce productivity," "the initial setup and layout of safety devices require time and effort," and "the use, verification, and validation of certified safety devices are necessary, which are also costly. In some cases, the user may find the work difficult to perform, require caution, or cause unnecessary stoppages, resulting in low productivity. Under such circumstances, it is easy to motivate workers to disable the safety function either intentionally or unintentionally, such as by maliciously disabling it, accidentally disabling it in an improvement attempt, or inappropriately reducing the human detection range, thus imposing a burden on managers and supervisors.

Since the concept of machinery safety that "people err in 100% of cases" is clearly stated in the international standards, it has not been reflected in risk assessment and risk reduction, despite the fact that the likelihood of error actually varies depending on human characteristics and conditions. On the other hand, the latest international standards on machinery safety (e.g., ISO13849-1:2023) propose a method to include human characteristics in the probability of occurrence of harm in risk estimation for determining the level of safety-related control systems. This indicates that the aforementioned issues have been recognized in the development of existing international standards in the field of machinery safety and should be improved. However, the published international standards do not mention the extent to which the probability of error differs depending on human characteristics. Under such circumstances, " collaborative safety," in which humans, machines, and the environment collaborate to achieve both safety and high productivity by sharing and utilizing information, has been proposed as a new concept of safety. Therefore, we have considered that it is possible to establish a risk assessment method that includes the concept of collaborative safety by clarifying the possibility of human error as a quantitative measure based on behavior analysis, on the premise that "the possibility of error differs depending on human characteristics". Based on this method, the reliability level required for safety-related parts of the control system can be optimized by considering human characteristics, and the available choices of safety devices can be expanded, contributing to solving the aforementioned problems of both production engineers and users.

In order to clarify how to apply collaborative safety at manufacturing workplaces, we measured the probability of people err, especially the probability of people taking actions that increase their risk, and the degree to which the application of technologies to achieve collaborative safety reduces their unsafe action rate. As a result, it was confirmed that the technology can be used for risk assessment and risk reduction measures. In addition, the requirements related to collaborative safety to sufficiently reduce the rate of unsafe behavior of people were examined.

Finally, the results of the study of the new risk assessment method were compiled into the collaborative safety guideline, which was first applied to applications where humans and machines coexist and collaborate within the scope of our company/group companies, and we confirmed that it not only improves safety and productivity, but also contributes to improving the well-being of the related people. Information and communication technology and sensing technology will continue to advance in the future, potentially further expanding the options for available safety devices. Since the concept of collaborative safety is widely applicable, the risk assessment methods proposed in the Guidelines for Collaborative Safety can be applied to fields other than the manufacturing field.

Keywords: Collaborative Safety, Risk Assessment Method, Human Characteristics, Manufacturing field

A Study of Safety Radar As a Three-Dimensional Electro-Sensitive Protective Equipment

Reiji Nishigaki (FUJI CORPORATION), Atsunori Hirano (FUJI CORPORATION) and Takeshi Nomura (FUJI CORPORATION)

Abstract. This paper investigates the intersection of safety standards, in particular ISO 13855, and the specific characteristics of three-dimensional radar electro-sensitive protective equipment (ESPE) in the context of industrial production systems. This study focuses on adapting ISO safety distance standards, originally tailored to optical ESPEs, to the capabilities introduced by the IEC TS 61496-5 standard for radar ESPEs. Conventional optical ESPEs present a trade-off between installation flexibility and required safety distance length to meet standard requirements because of their two-dimensional detection zone. In contrast, radar ESPEs can achieve both short safety distances and flexible installations due to their three-dimensional detection zone, which can be interpreted as distributed imaginary light curtains from the start to the end.

However, applying these parameters directly to the standards requires theoretical and practical consideration. This study provides fundamental insights into methodologies for maximizing the advantages of radar ESPEs while meeting safety distance standards. The section on theoretical framework explains radar detection theory and outlines the calculation of safety distance in accordance with ISO 13855. A case study is presented using a conventional series-fed two-patch antenna to demonstrate the radar ESPE's ability to detect a human fist within a specific three-dimensional zone. Additionally, this study showed that a fabricated radar ESPE can suffice the detection capability and the short safety distance can be achieved. The aim of this study is to contribute to the advancement of safety and efficiency in contemporary production environments.

Keywords: Safety Sensor, Safety Distance, Safety Radar, Electro-Sensitive Protective Equipment, Radar Cross Section

Innovative assistance system to prevent accidents on sliding table saws

Thomas Seifen (Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA))

Abstract. Serious accidents occur time and again on sliding table saws, as the operating personnel typically work with their hands very close to the saw blade. The protective device required by the related machine standard is the safety hood. Unfortunately, this protective device is often not set correctly, which means that serious injuries to the hands still occur time and again.

In 2019, the IFA conducted a proof of concept of a camera-based assistance system designed by a saw manufacturer. The camera system is designed to trigger a safe state when a hand approaches the hazardous area in a dangerous way. To detect a hand and track its movement, software is used that employs artificial intelligence (AI) to examine camera images for the presence of human hands. As soon as the system detects a hand in the camera image and thus diagnoses a hazardous situation, the saw blade is lowered under the worktable in a fraction of a second to prevent contact between humans and the saw blade. The system was tested by the IFA both in the concept proof at specification level and in a type examination until May 2022. Due to the AI component the system was not assessed as a protective device, but as an assistance system. There are currently no suitable standards for use or assessment for vision based protective device using AI technology. Assistance systems can help to gain experience with the use of AI technology.

The system has been awarded the German Occupational Safety Award 2021 in the "Operational" category. In November 2023, the International Social Security Association (ISSA) presented the manufacturer of the system with the triennial Safety Award.

Keywords: camera-based AI-system, assistant system, protective device, sliding table saw

Calculating the reliability of a zero energy state system

Pascal Poisson (École Polytechnique), Sabrina Jocelyn (IRSST) and Yuvin Chinniah (Polytechnique Montreal)

Abstract. In Canada and other industrialized countries, workers who are required to carry out tasks in the hazardous zone of a machine when performing repairs, maintenance or unjamming activities must follow lockout procedures, unless safe alternative methods exist and can be applied. In Quebec the occupational health and safety regulation has been updated recently and several articles have been added on lockout procedures. That regulation allows for alternative control methods in addition to the traditional lockout/tagout, as long as the risk assessment deems the residual risk level to be acceptable. This approach differs from the typical North American standard (CSA Z460), which emphasizes ensuring a zero-energy state.

In Canada the CSA Z460 standard in the control of hazardous energies is viewed as a reference in the area. Lockout procedures have been extended to the construction sector for the control of hazardous energies as well. The lockout procedure consists of the following steps: stopping the equipment, isolating the energies, applying individual locks, dissipating residual energies and verifying the absence of energies. Lockout procedures require lockout devices as well as training and audits. An important step in the lockout procedure is the verification step. Workers often neglect that step for various reasons. This article focuses on the use of dedicated safety electronic systems as an alternative to achieving a zero-energy state. These systems, rather than eliminating energy, control it to ensure workers' safety. They are characterized by their reliability and typically involve interlocking devices, such as door interlocks, safety scanners, and other safety mechanisms, during operational tasks.

The article also introduces a method for calculating the reliability of these zero-energy-state system, based on the ISO 13849 standard. This method aims to help businesses comply with both the local regulation and the CSA Z460 standard. It builds upon the work of Poisson et al. from 2016, who calculated a zero-energy-state system in scenarios involving complex energy return recuperation systems. This innovative approach could potentially replace the need for voltage testing or machine startups following a lockout procedure. This development is particularly relevant given the increased complexity of modern machinery and the challenges in ensuring that no other energy sources that could harm workers are present post-lockout. This approach could significantly change how businesses ensure worker safety and regulatory compliance.

Keywords: Lockout tagout, zero energy state, machine safety, CSA Z460, ISO 13849

Importance of Education and Qualification Systems to Embrace a Holistic Approach of Human, Technology, Management and Rule Formation for Advancing Safety, Health, and Well-being at Work

Toshihiro Fujita (Nippon Electric Control Equipment Industries Association), Masahiko Ariyama (Japan Certification Corporation) and Masao Mukaidono (The Institute of Global Safety Promotion (IGSAP)

Abstract. The concept of safety has evolved in conjunction with the social conditions and needs of each era, giving rise to various management methods and technologies. In the realm of safety management, the Vision Zero initiative, which originated in Germany and was proposed by organizations such as DGUV at the 20th World Congress on Safety and Health at work held in 2014, has evolved into the idea that organizational leaders should actively promote the "safety, health, and well-being" of workers. At the A+A Congress & Exhibition held in Dusseldorf in October 2023, presentations by DGUV and KAN conveyed a sense of nationwide Vision Zero promotion in Germany, and announcements from organizations such as ISSA, FIOH, and ORP were mostly dominated by the Vision Zero theme. Furthermore, at the 23rd World Congress on Safety and Health at Work in Sydney in November 2023, it is not an exaggeration to say that Vision Zero, promoting "safety, health, and well-being," was the most crucial theme, making it the most prominent trend.

On the technological front, safety measures have evolved in line with the technological advancements of the times. Machine safety and functional safety have been highly effective and widely practiced in manufacturing, serving as the core of current machine systems. The coexistence of humans and machines without physical guards has become increasingly prevalent not only in the manufacturing sector but also in the construction, civil engineering, and various service industries. This is evident with the widespread use of collaborative robots and Automated Mobile Robots (AMRs). In such scenarios, where there are no guards or physical boundaries between people and machines, achieving "safety, health, and well-being" has become extremely important.

To address this, the concept of collaborative safety, which involves connecting humans, machines, and the environment through Information and Communication Technology (ICT), was proposed in 2015, and Professor Dr. Masao Mukaidono delivered a presentation on this concept at SIAS2018. Subsequently, with the development of various technologies and the implementation of collaborative safety, there have been observable improvements in the well-being of workers in Japan. This indicates that the concept is progressing over time and showing positive outcomes in real-world working environments.

In the midst of such circumstances, regardless of the changing times, the most crucial aspect remains education, training, and qualification for individuals. In addition to the fundamentals, it is essential to ensure that individuals can comprehend and adapt to these latest trends. This applies not only to the designers and engineers of machines and systems but also to those managing working environments and individuals, particularly those in leadership roles. Education for everyone involved in the workforce, including those working on the ground, becomes crucial in the evolving societal norms. Understanding and deepening the knowledge of "safety, health, and well-being" in the current society require education and training, as emphasized by the 6th Rule of Vision Zero 7 Golden Rules. As societal norms continue to evolve, the importance of qualifications to measure people's understanding has become increasingly significant.

In Japan, under the collaboration with the Ministry of Economy, Trade and Industry (METI), the Safety Assessor Qualification System was established in 2004 under the leadership of Nippon Electric Control Equipment Industries Association (NECA). With the rapid proliferation of robots, the system has evolved into the Robot Safety Assessor Qualification System. This progression has been consistently presented at the SIAS conferences, including SIAS2007, SIAS2010, SIAS2015, and SIAS2018, detailing its development and effectiveness. At SIAS2021, it was reported that the Safety Officer Qualification System was established for management personnel to ensure a solid understanding of safety at the managerial level, not only engineers. Subsequently, Japanese corporate executives and managers have recognized the importance of this system, resulting in the qualification of over 3,000 individuals. The utilization of these qualification systems has extended to eight Asian countries, producing over 30,000 qualified individuals worldwide, and the number of adopting companies exceeds 2,500.

Especially, the concept of "collaborative safety" being promoted in Japan, as evident in presentations from other presenters from Japan, is not solely achieved through technology. It is realized through a holistic approach that encompasses four aspects: technology, people, management, and rule formation. Many Japanese companies have already begun implementing this approach. This paper will elaborate on this holistic approach, focusing particularly on the progress and future prospects in the areas of education, human resource development, and qualification. Specifically, this paper will report on Japan’s initiatives and future outlook highlighting the progress in the following three crucial perspectives:

1) Utilization, level of penetration, and benefits of Safety Assessor Qualification System and Robot Safety Assessor Qualification System in Companies

2) Concept, level of penetration, and benefits of the Safety Officer Qualification System as a mechanism to provide management with an understanding of safety:

3) Importance of qualification systems in human resource development for understanding and promoting new trends such as collaborative safety and Vision Zero

Keywords: Collaborative Safety, Safety Assessor Qualification Systems, Vision Zero

Safety Associates Council: Improving the competence of safety-qualified personnel and contributing to the reduction of occupational accidents.”

Hiroshi Matsuura (Japan Certification Corporation), Takahiro Uehara (Japan Certification Corporation) and Saori Taketa (Nippon Electric Control Equipment Industries Association (NECA))

Abstract. This paper focuses on the Safety Associates Council (SA Council), an organization of safety-qualified personnel.

The SA Council works across companies to improve safety competence (knowledge and skills) and contribute to society.

Its main activities contribute to the reduction of occupational accidents at manufacturing sites.

To reduce occupational accidents, those in charge of risk assessment, design, and regulation operation and management as well as rules such as safety standards and occupational health and safety management systems must have appropriate competence. In response to this need, Japan Certification Corporation launched a certification program of personnel competence from 2004 for engineers who design machinery and robot and for those who manage occupational health and safety.

Having appropriately competent and qualified personnel on the job site is critical to establishing a safe and secure work environment.

However, a shortage of safety qualified personnel remains an ongoing challenge. In recognition of this, we have established the SA Council.

The SA Council aims to contribute to the competence of qualified personnel and the prevention of accidents through specific activities for safety qualified personnel to contribute to safety and wellbeing in their respective roles. Through the efforts and achievements of the SA Council, we hope that qualified personnel will be recognized by society and that their contribution to the creation of a safe working environment will be appreciated.

Keywords: Organization of safety-qualified personnel Contribute to society, Reduction of occupational accident, Works across companies

Proposal for "Anshin Stop Switch" based on behavior analysis

Yoshihiro Nakabo (AIST), Kazutsugu Suita (Kawasaki Heavy Industries) and Keiju Anada (Atliere)

Abstract. In the current, generally accepted machine safety, safety is ensured by reducing the risk to an acceptable risk level in the three-step risk reduction process, from the first step of ensuring intrinsic safety to the second step of safety protection by machines. On the other hand, the third step, ensuring safety by machine users, is dependent on uncertain human behavior, and therefore, in principle, it should only be used after the risk has been reduced below the acceptable risk level. In contrast, the concept of human-machine collaborative safety has been newly proposed in recent years, whereby safety is further ensured when humans and machines work together and cooperate with each other by having humans take safer actions. In addition, various studies have begun to consider the possibility of using information technology, AI, and sensors to promote safe human behavior as an effective way to achieve this.

In this paper, we discuss the possibility of human-machine collaborative safety using an emergency stop switch that stops a robot when a human recognizes an abnormality.

As a comparison, in the case of the conventional power-off type emergency stop switch based on machine safety, even if danger is avoided by pressing the switch, it generally takes time to restart the robot system after stopping and shutting off the power, and as a result, the operator tends to hesitate to press the emergency stop switch.

On the other hand, if there is a function that allows the robot to pause its operation while energized, workers would press the switch without hesitation, which would promote the use of the pause function and ensure greater safety. In this paper, we define an emergency stop function that takes into account the principles of human behavior as an "Anshin Stop Switch," and propose it as an example of human-machine collaborative safety.

The definition of the safety function of the "Anshin Stop Switch" should satisfy the following three points.

(1) A stop function for safety to be used in a human-in-the-loop.

(ii) A device that lowers the psychological and physical hurdles to use.

(iii) It shall be designed to minimize deviation from normal operation based on the assumption of frequent use.

In order to confirm this, we conducted a questionnaire survey of workers in a robot restaurant that is actually in operation. Specifically, when a worker presses the power-off emergency stop switch or the "Anshin Stop Switch" equipped with a function to temporarily stop the robot while it is energized when he or she recognizes an abnormality, the effect of each on danger avoidance and the effect on his or her future behavior were confirmed. The results were modeled and analyzed together with our proposed "Safety Behavior Design Diagram" based on behavioral analysis. As a result, we were able to confirm the basic effects of the "Anshin Stop Switch".

Keywords: collaborative safety, machine safety, functional safety, behavior analysis, emergency stop, service robot

Use cases of specific initiatives leading to Vision Zero promotion and ISO 45001 certification, which are effective in building a safety culture

Masao Dohi (IDEC CORPORATION), Masaki Nobuhiro (IDEC CORPORATION) and Hiroshi Fukutsuka (IDEC CORPORATION)

Abstract. The IDEC Group has set a goal of "becoming the world's number one company pursuing and realizing safety, Anshin, and wellbeing." Since its establishment in 1945, the IDEC Group has been developing safety technologies, training safety personnel, and improving occupational safety and health at manufacturing sites, while actively participating in international safety-related standardization activities.

The company has also actively promoted Vision Zero campaigns, an international initiative for occupational safety, healthand wellbeing. To date, occupational safety and health activities have focused on risk reduction in the negative areas such as injury, illness, and mental disorders. In other words, activities to reduce the negative to zero were the main focus. In the future, we should also focus on positive activities in the area of positivity, moving from zero to positive. The zero to positive activities in safety, health, and wellbeing, in other words, are to enable workers to work safely, healthily, energetically, and with a sense of fulfillment.

Vision Zero activities are activities to pursue safety, health, and wellbeing, and to achieve not only the conventional "from minus to zero" but also further "from zero to plus," and as one of the specific activities, IDEC is working to ensure that all of its production sites in Japan are certified in accordance with the international occupational health and safety management. As one of its specific activities, IDEC has been promoting the acquisition of ISO 45001 certification, an international occupational health and safety management system standard, at all of its production facilities in Japan.

ISO 45001 is an international standard that specifies the requirements necessary to realize a system of continuous improvement for the purpose of preventing work-related injuries and illnesses among workers and providing a safe and healthy work environment, or occupational safety and health (OSH).

In 2019, the Takino Plant in Hyogo prefecture Japan, one of IDEC's main manufacturing sites, obtained ISO 45001 certification, and since then, the number of sites covered by this certification has been increasing each year, with all five production sites in Japan achieving certification by 2022, and efforts currently underway to obtain ISO 45001 certification at all overseas sites.

All of IDEC's domestic facilities that have been certified are working to build a higher level of IDEC's safety culture, and in recognition of their achievements, IDEC was awarded the Chairman's Award of the Japan Industrial Safety and Health Association (JISHA) in 2022 and the Vision Zero Award from the International Social Security Association (ISSA) in 2023.

This paper introduces IDEC's process for fostering a culture of safety and use cases of activities that are particularly effective among the various activities being implemented to "build an IDEC safety culture at a higher level".

1. IDEC's four-step process for building a culture of safety

2. Activities that are particularly effective in building a culture of safety

- Top Commitment

- Management system implementation methods

- Activities that encourage full participation and respect the voice of employees

- Human resource development activities to enhance individual abilities and motivation

- The use of KPI (Key Performance Index) using the 7 Golden Rules proposed by Vison Zero

Keywords: Vision Zero, Safety and Anshin, Collaborative Safety, Safety2.0, Holistic Approach

Integration of Risk Assessment into the Cobot Programming Workflow

Robert Scharping (Fraunhofer IFF), Roland Behrens (Fraunhofer IFF) and Norbert Elkmann (Fraunhofer IFF)

Abstract. The CE marking process is mandatory for collaborative robot systems (cobots) in order to declare conformity with all harmonized safety standards and, thus, with the machinery directive. A crucial part of the process is the risk assessment, in which hazards are identified and evaluated according to their associated risks. A correct and comprehensive risk assessment is not an easy task. It usually requires long-term experience or external support that, given the associated costs, can be especially burdensome for small and mid-sized companies. The author believes this is one reason why companies are currently hesitant to invest in cobots and associated technologies. Additionally, the risk assessment as done today is typically static and only applies to a particular configuration of a robot application as determined by trajectories, environment and task. Changes to the application require a review of the existing risk assessment documents.

In contrast to the risk assessment process, which has not changed much in recent years, the methods for cobot programming have dramatically improved in the recent years. Most cobots on the market can be easily programmed without specific knowledge or training. A cobot can be deployed and programmed with relatively little effort, but the time-consuming and primarily manual executed risk assessment is done since decades ago. Aanecdotal experience points to strong underrepresentation of cobots that run in operating mode “Power and Force Limiting” (PFL), where physical contact is allowed as long as the robot does not exceed the biomechanical limit values of ISO/TS 15066. While PFL offers many advantages over other operating modes such as maximum flexibility, minimal footprint and reduced costs, the procedures associated with the validation measurements represent a high burden. Thus, most cobots that are in industrial operation are actually either installed with safety fences or with other operating modes such as speed and separation monitoring (SSM) instead of PFL.

In this article, we present the concept of a digitally-assisted risk assessment that directly addresses the aforementioned challenges, specifically the high effort, costs and uncertainty of the current procedure. The solution integrates the risk assessment directly into the programming environment of a cobot. This close integration allows for the identification of contact hazards for each robot movement by adding information about body parts at risk, contact type and contact point to the robot program. Once all hazard were described, an essential part of the risk assessment is completed. Additionally, this information is used in combination with a simulation to determine the maximum allowable speed whereby the robot still complies with the biomechanical limits of ISO/TS 15066. These calculated speeds are then used to determine how fast the robot may move in the respective hazard profile while complying with the limit values and are subsequently used for the robot movement. The digital risk assessment, simulation-based validation and hazard-based speed control of the robot movement was integrated into a demonstrator and evaluated in a usability study. The results indicate a significant improvement over the current standard in terms of usability, time and costs.

We also see further advantages for cobot end-users. Whereas a risk assessment is traditionally executed by a safety expert who is responsible for a wide range of applications, in our case, the robot programmer who has clear and direct knowledge of the processes they are implementing is responsible for this task. Software assistance and wizards guide non-experts through the risk assessment process, thus lowering the barriers to entry. This saves time and reduces misunderstandings. Another advantage is the granular view of the process and safety mechanisms involved. Typically, a worst-case situation for the whole process is used to determine maximum speeds. Our approach allows for different operating modes and different speeds for individual movements, and can offer an optimal balance between safety goals and cycle time needs. In conclusion, our concept will make the use of cobots simpler, especially for small and medium-sized enterprises.

Keywords: risk assessment, simulation-based validation, collaborative robots, power and force limiting, biomechanical limits

Design and Development of a Roaming Wireless Safety Emergency Stop

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Abstract. In today's industrial factory automation with a high degree of autarky and numerous autonomous systems, human intervention in the event of an unexpected malfunction or even a planned maintenance becomes an inconvenient but necessary and unavoidable task, as it always increases the risk of accidents and injuries and may interfere with the flow of lean manufacturing processes. If work has to be carried out within a production line, all neighboring parts of the system shall remain productive and only the affected machine must switch to a safe state in case of an emergency stop (E-Stop). Additionally, the goal of mass customization requires flexible shop floor layouts, with movable production components being quickly adapted to changing requirements and modular production cells [1]. Dynamic industrial environments consist of production lines that often span several automation cells, requiring a communication system that supports roaming between cells without compromising safety. These two aspects are, among others, the motivation for the development of a functional safe wireless communication protocol, the realization of a wearable emergency stop switch and the extension of this communication system with roaming functions to cover multiple automation cells.

The proposed wireless communication system introduces an enhanced safety solution with a flexible and partially distributed implementation of an E-Stop function for multiple individual or interconnected automation cells in modular industrial factory automation use cases. The portable E-Stop could either roam between radio cells within one automation cell using handover procedures to ensure the highest availability with short but defined timeouts or connect and disconnect to automation cells providing the safety function only when required by the presence of a human or, e.g., also a robot or an AGV.

The functional safe wireless communication protocol in [2] combines the system architecture and basic communication algorithm of IO-Link Wireless (IOLW) [3] and the safety requirements and principles of IO-Link Safety (IOLS) [4]. Recognizing the ongoing discussion and the inherent security challenges in wireless communication systems, especially in safety-critical applications, the proposed solution integrates encryption algorithms and authentication protocols in an underlying security layer to follow security-for-safety requirements of a bit error rate up to 0.5, according to [5], [6]. The roaming feature of IOLW is used and adapted to extend the IO-Link Wireless Safety (IOLWS) application over multiple radio cells and cover the entire automation cell. Therefore, one or more IOLWS-Masters are strategically placed within each automation cell [7], ready to connect to the pre-configured IOLWS-Device providing the E-Stop switch. In addition to the E-Stop, other functional safety or conventional (i.e., non-safety) IOLW sensors and actuators may be integrated, as proposed in [8]. This leads to improved reliability, flexibility, and adaptability in industrial automation while preventing the system from unauthorized access as required by the EU Cyber Resilience Act [9].

An experimental setup as proof of concept is developed to optimize the cell switching and handover mechanisms on the one hand, and to evaluate the performance of the system on the other. The setup consists of two IOLWS-Masters with distinct radio cells and an IOLWS-Device with a preconfigured connection to both masters. In a wired setup, the connections are realized by programmable attenuators emulating different radio channel scenarios. A higher-level controller supervises the cell handover mechanism based on Received Signal Strength Indication (RSSI) and Link Quality Indication (LQI) in the generic scenario. In a more complex setup, the controller simulates additional hardware as e.g., light curtains, switches and other sensors to act as the functional safety equivalent of a “Demilitarized Zone” (DMZ) with well-defined separation/handover of the safety functions.

The results affirm the safety roaming suitability of the system for different use cases based on the evaluated handover duration and depending on the characteristics of the hazard (machine speed, range). As part of the final discussion, the system's potential to increase flexibility, availability and safety in automation applications in dynamic production environments is assessed. Also advanced features for a wireless roaming E-Stop, such as the use of AI for intelligent and predictive cell handover, are considered.

Keywords: functional safety, wireless, IO-Link Wireless, roaming

Proposal of Method to Consider Supporting Actions by Caregivers in Risk Evaluation of Robotic Devices for Nursing Care

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Abstract. Robotic devices for nursing care proposed so far can be roughly divided into two categories: those that are operated by the elderly or disabled person themselves who needs assistance and those that require a caregiver(s) to accompany the person always while the device is in operation. In the latter case, risks of harm that could occur after the device detects an abnormality and stops, such as, falls on the same level, etc. are simply recognized as “residual risk” in the risk assessment conducted by designers during the developing stage of devices. And therefore, it is common practice to specify the measures for the risks as "appropriate actions taken by the caregiver to prevent the accident or reduce the severity of that harm (hereinafter referred to as "supportive actions"). However, the feasibility and effectiveness of such measures for residual risks have not always been verified in detail. In fact, the risk assessments of designers have been completed with the expectation that, as long as the necessary actions are described in instructions or manuals, these actions will be learned through trainings of caregivers at the installation/commissioning and will be implemented in necessary situations without fail.

In this report, we propose a method to evaluate the appropriateness of the caregiver's supporting actions that are requested by the designer to reduce the residual risks and to reflect the obtained results in the risk assessment of the robotic nursing care devices, by referring to the evaluation of accident controllability stated for the risk analysis of safety control systems in functional safety standards of the road vehicles, the earth-moving machinery and the agricultural machinery.

The guidance on the risk analysis to determine the required performance levels for SRP/CSs in ISO 13849-1:2023(4th edition), has introduced contents regarding the characteristics of exposed person(s) and necessary operation(s), such as skill level of the person(s), possibility of recognition/awareness and complexity of the operations, in the evaluation of parameter P expressing the possibility of avoiding or limiting harm.

On the other hand, in the field of functional safety of road vehicles, earth-moving machinery and agricultural machinery, when the required ability of the SRP/CS to perform an intended function is determined, operations and behaviours taken by the driver and/or involved persons to avoid accidents are considered in estimating the necessary risk reduction, and thus, criteria to evaluate their feasibility/achievability are established as “Controllability”.

From the above, as aspects that influence the achievement of the caregivers' supporting actions against the residual risks after the stoppage of robotic nursing care devices, three factors of “foreseeability of the device stop”, “time to initiate action” and “restriction of caregiver” are listed to qualitatively evaluate the achievability of required supporting actions based on the controllability specified for earth-moving machinery, and the method to reflect the results in the risk assessment of the device is proposed. Furthermore, through concrete examples of possible hazardous events during the use of robotic nursing care devices and specified supporting actions, an alternative method is also discussed in which the achievability of the supporting actions is quantitatively examined by replacing the above three factors with the success rates estimated from the results of subject experiments. While this research is still in its infancy and the proposed method is not fully established as a tool for considering all supporting actions, it is expected to help designers who need to identify improvements in mechanisms, control features or operating conditions to facilitate the achievement of caregivers’ supporting actions during the developing stage of devices.

Keywords: machinery safety, risk assessment, robotic nursing care device

Promotion of Standardization Activities on "Collaborative Safety"

Tatsuo Takeshige (Ministry of Economy, Trade and Industry), Takahiro Takahashi (Ministry of Economy, Trade and Industry) and Kenjiro Ueda (Ministry of Economy, Trade and Industry)

Abstract. Recently it is commonly understood that one of the biggest issues in manufacturing industry is a lack of working force because working-age population is gradually declining. As a government-level measure, this industry is actively working on study and development for introduction of support of human work using machines to cover labor shortage.

In discussion of introduction of machine support, we cannot avoid considering “safety” between human and machine. New concept ”Collaborative Safety” is explained in IEC white paper that Collaborative safety is achieved when humans, machines and the operational environment share digital information with one another, communicate and collaborate. Technical measures related to safe collaboration between human and machine will be essential to realize machine support to human work. These technical measures based on “Collaborative Safety” concept would be widely utilized not only in manufacturing industry but also in medical, agriculture and construction industries.

The IEC white paper “Safety in the future” has been published in 2020 and we are still diligently promoting “Collaborative Safety” concept through activity of developing the IEC guideline “GUIDELINES FOR SAFETY RELATED RISK ASSESSMENT AND RISK REDUCTION FOR COLLABORATIVE SAFETY SYSTEM”. Developers/Users who try new concept and/or technology would be likely to face difficulties to introduce such concept/technology. To help this situation, we believe standards documents will be useful references and eliminate a barrier to introduce them into their business.

To widely propagate “Collaborative Safety” concept, we are necessary to develop and publish some more documentations such as guideline, technical specification, and conformance etc. As a result of this activity, international standardization of “Collaborative Safety” will contribute human well-being.

To realize “Collaborative Safety” concept, wide range of technologies would be required, such as not only basic manufacturing technologies but also low-latency communication technologies, various kinds of sensing technologies, cyber security technologies etc. In this paper, we present measures and focusing technical areas etc. from international standardization point of view.

Keywords: Standardization, Collaborative Safety, safety between human and machine

Enhancing Safety and Usability in the Design of a Powered Exoskeleton for Spinal Cord Injury

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Abstract. A powered exoskeleton, described as a robot that autonomously generates walking motions, is considered beneficial for gait rehabilitation in individuals with spinal cord injuries (SCIs). This technology has the potential to restore their motor function and facilitate their seamless reintegration into daily life and work. Previous clinical reports and systematic reviews have highlighted the positive impact of exoskeletons in helping individuals with paraplegia regain walking independence. However, persistent challenges such as device malfunction, skin injuries, misalignment, user error, and falls have also been identified. Other reported issues include problems with size and weight, as well as fitting issues related to lower limb alignment. Additionally, the safety of exoskeletons depends heavily on the assistance of caregivers. This emphasizes the importance of designing for safety to minimize risk for both SCI users and their caregivers, while still maintaining usability.

At the SIAS 2021 conference, we presented a safety checklist for individuals with SCIs and their caregivers who use exoskeletons. The checklist focuses on human support perspectives. In this conference, we will present the results of a study on the safety and usability of a powered exoskeleton designed for individuals with SCIs from an engineering perspective. The aim is to mitigate risks associated with both the exoskeleton itself and its users. The exoskeleton prototype has basic features, including hip and knee joint actuators controlled by a programmable logic controller to assist with walking, standing, and sitting movements. The actuator is equipped with a 1:101 reduction gear and a brushless DC motor that can generate a maximum torque of 90.9 Nm, satisfying the torque requirements for standing up from a chair. The design incorporates a gait trigger sensor that activates the gait sequence based on the forward trunk tilt of the user, taking into account potential neuroplasticity in voluntary movements.

Additionally, the prototype includes an adjustable frame to fit the human body size and lower-limb alignments, addressing variations such as X- and O-legs while also reducing the risk of skin injuries. The operating interface is integrated into the grips of the Lofstrand clutch, allowing direct control by the patient. The design also incorporates intentional choices to minimize the risk of user errors. The mode selection switch is located on the right grip, while the stop switch is on the left grip. These switch outputs are transmitted to the exoskeleton controller via Bluetooth. Voice guidance is also available to aid in recognizing and transitioning the exoskeleton's operating state. Caregivers can access various switches on the controller box for start/stop operations.

A preliminary fitting test with healthy participants confirmed the frame's adjustability to human lower limb shapes, validating the effectiveness of adjustment functionalities. The operation test demonstrated the normal execution of target motions under unloaded conditions. Subsequent motion analysis with a markerless motion capture system confirmed the safe performance of standing-up, walking, and sitting-down movements in healthy participants wearing the prototype.

The operating interface demonstrated effectiveness during actual walking, ensuring smooth and reliable stopping movements without unexpected motions. A single switch enables both normal and emergency gait stopping, with each procedure and return method operating independently, enhancing control and safety. The prototype shares basic functions with traditional exoskeletons, such as assisting with walking, standing, and sitting. However, it also introduces innovative features, such as a joint angle adjustment mechanism, a wireless operating interface, and an emergency stop switch, to improve overall functionality, safety, and usability. To ensure future clinical application, the device requires further refinement and fine-tuning of gait parameters.

Keywords: powered exoskeleton, spinal cord injury, assistive technology, safety, usability

Examination of unsafe behaviour and conditions causing human errors during human-machine interaction in a collaborative production system

Kazunari Tsukiyama (OMRON Corperation) and Rieko Hojo (Nagaoka University of Technology).

Abstract. Conventionally, in the field of machine safety, there are three main methods for reducing risks of machinery: 1) Inherently safe design: eliminating the hazardous source (the dangerous part of the machine) or reducing risk the risk associated with hazards; 2) Stop: stopping the machine when an individual enters the dangerous area of the machine; allow individuals to enter the hazardous area of the machine by shutting it down; 3) Isolation: providing guards or enclosure beyond hazardous area so that people cannot reach the area.

However, the current introduction of new technologies, such as collaborative robots or autonomous mobile robots, into the marketplace and manufacturing sites has created difficulties in applying these methods, especially stop and isolate.

In response to this situation, an urgent need is to establish a system safety approach that can be adapted.

Technological innovations suggest that machines can be made safer by developing new safety functions rather than stopping and isolating them. There is also an emerging trend to utilize human factors in risk assessment/risk evaluation rather than relying solely on conventional safeguards. This movement is beginning to be explored in various fields of safety management systems.

In industrial workplaces, many collaborative tasks are performed by machines and humans, and there are increasing opportunities for humans and robots to get closer together. On the other hand, many aspects still depend on human attention, such as the worker adjusting their movements to match the robot's, and there are concerns about the stress and burden on workers. In the future, a system safety approach that is a systematic and reliable management system that is not affected by stress and burden on workers will be essential. However, at present, there is not enough information available to determine the specific conditions that lead to unsafe behavior and human error when working with a collaborative production system.

This paper presents the results of simulated a workplace where collaborative robots and workers worked together, tried collaborative work under various conditions, and identified conditions that induced unsafe behavior and human errors. For example, various conditions were combined, such as the appearance rate of defective products, the operating speed of collaborative robots, the procedure from E-stop to restart, manual work, and more. Then, the appearance rate of unsafe behavior or errors, stress, and workload were measured and analyzed as evaluation indicators.

Keywords: risk assessment, safety of machinery, occupational safety, behavior analysis, well-being

Case Study of Conformity Assessment based on ISO 31101 and Safety management systems of Robotic Services

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Abstract. In recent years, in response to the declining birthrate and aging society that the world is facing, Japan has taken the lead in dealing with the problem of labor shortage.

To solve these problems, service robots have begun to be introduced in various industries.

For example, service robots are used for food delivery in restaurants, floor cleaning and security at train stations and airports, destination guidance, and in-facility and indoor delivery operations.

Unlike industrial robots used in factories, service robots are used in public places, i.e., in environments where the general public is present.

Therefore, it is important to ensure safety intended to coexist and furthermore collaborate and cooperate with people without harming them.

Until now, safety has been ensured by service robot developers installing safety functions in their robots.

In addition, since service robots are applicable to various use cases and may be used in various environments, it has been difficult for robot manufacturers alone to ensure safety.

Especially in the early days of service robots, when there were few examples of social implementation, robot manufacturers had to be careful to ensure that robots could coexist with humans, and they tended to demand excessive safety from robots.

This led to longer robot development periods and higher development costs, and the widespread use of service robots did not progress as expected.

Essentially, safety is not only ensured by the safety design implemented in the robot by the robot manufacturer, but also by the way the robot is used, the environment in which it is used, and the way it is operated.

This means that the user can participate in risk reduction activities through risk communication, which is expected to achieve total safety assurance of service robots at a reasonable cost.

We also believe that this will accelerate the social implementation of service robots.

In Japan, against this background, the JIS standard for operational safety management of service robots (JIS Y1001) was published in 2019.

Moreover, ISO TC299/WG7, which promotes standardization in the field of robotics and is chaired by the National Institute of Advanced Industrial Science and Technology (AIST), discussed the standardization of operational safety management for service robots in an international conference, and “ISO 31101 -Robotics Application services provided by service robots-Safety management systems requirements” was published in November 2023.

This standard specifies safety management systems to be followed by application service providers (ASP) offering robotic services.

In this paper, first, Japan Quality Assurance Organization (JQA) developed a hypothesis on the merits of applying ISO 31101 and conformity assessment by third party from the following perspectives.

(1) Robot service operation system based on ISO 31101 leads to the benefit of users.

(2) Robot service operation system based on ISO 31101 leads to benefit and service improvement for service providers.

(3) Benefits of conducting third-party conformity assessment based on ISO 31101.

(4) Competence of evaluation organizations and evaluation personnel required for ISO 31101 evaluation activities.

Next, Kawasaki Heavy Industries, Ltd. conducted a case study with AIST and JQA to test the hypothesis by targeting the service at a robot restaurant operating at the Future Lab HANEDA.

The case study focused on the following four aspects.

(1) Identification of stakeholders to operate the robot restaurant service.

(2) Organizing stakeholder roles to operate the robot restaurant service.

(3) Identification of documents to be documented required by the standard

(4) Analysis of gaps between the requirements of the standard and the documentation used in the actual operation of the robot restaurant service.

As a result, we were able to indicate issues and directions for the establishment of a robot service operation system.

In conclusion, ISO 31101 is expected to be effective in promoting the spread of service robots, but it also became clear that there is a need to promote the benefits of ISO 31101 and support its introduction so that application service providers (ASP) can widely utilize it.

Keywords: ISO 31101, Service robots, Safety management system, Conformity assessment, Case study

A Case Study of Collaborative Safety Measures Using Enabling Switches to Make Self-Propelled Mobile Elevating Work Platforms Safer and Improve Well-being of Workers

Masaki Nobuhiro (IDEC Corporation), Tomohito Mori (Daiwa House Industry Co., Ltd.), Tatsunobu Nakai (IDEC Corporation) and Masao Dohi (IDEC Corporation).

Abstract. The self-propelled mobile elevating work platforms are widely used in construction sites, facilitating work operations. While an operator is responsible for their vertical movement operations, distractions such as focusing on the next work area or preparing work tools may lead them to overlook the presence of upper structures. This distraction could result in serious accidents, including fatalities or severe injuries, as operators may become caught between the platform railing and the upper structure.

Due to the simplicity of the movement of the work platform, safety has long relied on human attention, but this approach has not effectively prevented serious workplace accidents. To address this issue, we developed a 3-position enabling switch and a collaborative safety system using sensors to measure the distance to upper structures and installed them on mobile elevating work platforms at construction sites. The 3-position enabling switch, required for safety in ISO and IEC standards for robotic teaching devices, effectively communicates human reflexive actions in the face of danger to the machine. We were the first in the world to integrate the 3-position enabling switch into construction machinery, developing a safety device that conforms to the concept of collaborative safety.

The introduction of this safety measure not only reduces the risk of workplace accidents but also could increase creativity and productivity by fostering a sense of security among workers, allowing them to work with confidence and enhancing overall workplace well-being. The safety system continuously measures the distance to upper structures during platform elevation, monitoring the risk of workers getting caught. It automatically halts ascent when approaching a pre-set distance, alerting the operator to a hazardous condition. If further elevation is necessary for the task, the operator must release their hand from the 3-position enable switch and ascent control device, conveying their intention and demanding heightened attention during elevation.

In the event of accidental contact with an upper fixed object, the 3-position enabling switch signals the operator's surprised reaction to the mobile elevating work platforms, promptly stopping ascent and preventing a serious accident.

The survey conducted at the construction sites where this system was implemented revealed that the system not only improves the physical safety of workers but also enhances their sense of security in performing ascent and descent operations, minimizing the likelihood of serious accidents. This, in turn, contributes to the overall mental and physical safety and well-being of both workers and supervisors.

If we consider high-risk work environments as the negative domain, achieving a state where risks are reduced to an acceptable level through safety measures is represented as zero, and further, creating a positive domain where individuals can work forward with a sense of ANSHIN (ANSHIN means a sense of trust and assurance without fear or stress). In this context, this safety measure serves as an example where workers and managers were able to operate in a positive psychological state.

This paper reports on the details of this collaborative safety measure, which received the highest commendation at last year's safety convention hosted by The Japan Construction Occupational Safety and Health Association, and the psychological effects and well-being it has brought to the workforce.

Keywords: construction machine, construction site, elevating work platform, collaborative safety, Safety2.0, well-being, ANSHIN, enabling switch, safety measure

The study of design and operation of collaborative machines - risk assessment and communication

Hiroo Kanamaru (Mitsubishi Electric Corporation).

Abstract. Information technology (IT) is creating a new class of highly automated machines. By automating processes that were previously decided by humans, autonomous machines can now work on behalf of and alongside humans. We call that "collaborative machine".

Still now, it has been possible for humans and machines to exist together in a specified space. Spaces where humans and machines coexist are also dangerous spaces. Therefore, within the coexistence space, machines are subject to restrictions on their movements (speed, torque, range, etc.) to avoid injuring people. When using such the coexistence machine, there are two concepts of coexistence space: a fixed static space and a dynamic space that changes from moment to moment. For example, it is a static space where the robot base is equipped with area sensors and the robot operation is changed based on the horizontal distance from the robot. On the other hand, it is a dynamic space that is equipped with an area sensor on the AGV and applies the brakes based on the relative distance from the AGV. By advances in sensor technology, coexisting machines would enable accurately measure and manage dynamic spaces, and improve machine safety, installation size, and operational efficiency.

In addition, a new type of machine that is attracting attention is the "collaborative machine". Collaborative machines are also a type of coexisting machines because humans and machines can work together in a coexisting space. The difference between both is that in collaboration systems, humans and machines work together toward the same goal. Collaborative machines observe humans and understand what tasks they are performing, their procedures and operating speeds, and then adjust their own tasks and their own actions to improve the overall efficiency of humans and machines. That is, a collaborative machine is a coexisting machine that is aware (programmed) of human behavior and its support in collaborative work.

Similarly, humans who handle collaborative machines can improve overall work efficiency by understanding (and receiving training) the machine's functions and performance. When humans and machines mutually understand each other's roles and capabilities, overall work efficiency can be improved.

However, material defects, machine failures, systematic failures and human errors cause machines to slow down and, in some cases, take avoidance or safety measures to avoid harm to humans. These avoidance and safety measures must be prepared (programmed) in advance to determine which measures to take in which situations. The programs that include these safety measures are highly application dependent. Therefore, collaborative machines can be realized by adding and expanding collaborative work programs to the coexistence machine platform. As with PLCs and robot controllers, the role of the system integrator is important.

The design method for collaborative machines will be considered in the same way as the safety design of current machines.

- Analysis of requirements, limitations, and specifications of collaborative machines
- Identification of hazards in collaborative machines (and the system)
- Risk analysis and estimation
- Design and realize safety measures (risk reduction measures)
- Risk evaluation for safety measures

In the case of collaborative machines, the operation and specifications of the machine change depending on the movement of the personnel task, so it is necessary to collect more detailed information. In addition, the number of risk analysis scenarios will increase because of the combination of the conditions between humans and machines. Countermeasures will be designed for almost of these assumed accidents. In particular, machines need models to monitor and judge a person's movements in order to identify what the person is trying to do.

To operate a collaborative machine, there are also requirements to users. First, it is necessary for workers to have training on collaborative work with the collaborative machines. If workers are inexperienced, the collaborative work between them and machines would slow down. The result of work might be as same as the basic coexisting machines. The physical and mental conditions of the workers on the day must also be taken into consideration. Of course, the user must strive to maintain the machines and working environment in the best possible condition. By periodically checking the workability and quality of the collaborative work, it is also necessary to review machine programs, installation, and operating procedures. In this case, the user exchanges his opinions with the integrator regarding the operability and limitations of the machine, including safety aspects. For collaborative machines, such risk communication is important for improving collaborative work.

Currently, standards for collaborative robots have been published, but they remain within the category of coexisting machines discussed in this article. The requirements for the collaborative system are under discussion. Including these issues that machines designed to monitor humans' behaviors and humans trained to understand machines.

This paper analyzes the roles of collaborative machines, workers, and users that realize collaborative work, and describes the design and operation of collaborative work systems.

Keywords: COLLABORATIVE MACHINE, COEXISTANCE MACHINE, RISK ASSESSMENT

Regulation and standards for Robotics and Autonomous Systems in the UK machinery sector

Nicholas Hall (Health and Safety Executive, UK) and Colin Chambers (Health and Safety Executive, UK).

Abstract. HSE has undertaken research to identify ways to help ensure the safe implementation of new and emerging technologies in the UK machinery sector. The research aimed to answer the following questions:

• What is already known about the coverage of existing regulations, standards and guidance with regard to new and emerging technology?

• Where does industry turn to for guidance with regards to implementation of new and emerging technology?

• Which topic areas require immediate help and guidance, while the current standards catch up with technology?

The research adopted a three-step approach to answer the above questions. First a review of relevant standards and guidance documents was conducted to identify potential gaps in their coverage of these novel technologies. Second, to complement the standards review and gain qualitative insights, two interactive workshops were undertaken. Participation included representatives from manufacturers, systems integrators, end users, and academia. The workshop analysis, which is the focus of this paper, considered five specific new technologies: Autonomous Mobile Robots (AMR), Autonomous Agricultural Vehicles (AAV), Collaborative Robot Applications, Artificial Intelligence/Machine Learning (AI/ML), and Cybersecurity. Third, a questionnaire was sent out to a number of relevant companies and organisations, with an invitation to attend the workshops and/or to complete and return.

The first workshop covered AAVs and the use of robotics in the agricultural sector, the second looked at the manufacturing sector and use cases for AMRs and collaborative robotic applications. The workshops used case studies to consider different levels of autonomy and potential future implementations of innovative technologies, for example, using machine learning to control equipment and make safety decisions.

The research identified a number of areas where the use of new technologies meant that there were different risks associated with machinery. It concluded that the current UK legislation can be applied to new technologies, but that there may be a need for industry guidance to help in those areas where standards are yet to catch up with recent technological innovations. The results of this exercise highlights areas of future research, suggests areas for development of industry guidance, and will feed into standards development to help ensure safe design and implementation of autonomous systems in the UK and beyond.

Keywords: RAS, Standards and Guidance, Machinery

Effects of Interspace and Safety2.0 implementation on safety and well-being in human-robot collaborative environment

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Abstract. The manufacturing industry, exemplified by Factory Automation (FA), is evolving to address new industrial challenges such as a shrinking workforce, diversification of human resources, and increased complexity of needs. In pursuit of flexible production systems, there is a growing trend in which humans and collaborative robots and/or Autonomous Mobile Robots (AMRs) coexist and/or collaborate in the same space. In addition, collaborative robots for cooking and service robots for serving and last-mile delivery are being introduced in restaurants and various other settings, expanding presence of human-robot collaboration and/or coexistence in the general community, regardless of age or gender.

In such situations, it is essential not only to improve operating efficiency and implement more user-friendly functions, but also to ensure a certain level of safety and ANSHIN*. (*ANSHIN: a Japanese word that means a sense of trust and assurance without any fear or stress) As a response to these needs, the concept of collaborative safety, which is "a concept in which humans (humanities), technology (natural science), and organizations/environment (social science) share information and work together in harmony to ensure safety," utilizing information technology represented by AI and ICT, and its technological aspect, Safety2.0, is attracting attention and being increasingly introduced in factories, construction engineering and logistics. Safety2.0 is a technological measure that facilitates the sharing of information among humans, objects/machines, and the environment, enabling optimal human behavior and machine control. Safety2.0 not only focuses on negative aspects such as reducing risks and accidents but also enhances the positive aspects such as achieving a balance between productivity and safety, as well as improving well-being , including ANSHIN and satisfaction.

Methods of information sharing have evolved from person-to-person (language), from thing to human/human to thing (HMI: Human Machine Interface), and from thing to thing (correspondence). While various digital spatial description formats have been developed as unique approaches for information sharing in fields such as FA and construction, the lack of compatibility between these description formats poses a challenge in achieving effective information integration. Thus, there is a proposed need to enhance mutual information coordination between physical space and various digital spatial description formats. Providing a common foundation for information coordination serves as a spatial description format is referred to as the “Common Ground.”

Furthermore, within this Common Ground, the boundary region between physical space and digital space is referred to as the "Interspace." In this Interspace, the standardized spatial information derived from the Common Ground turns the entire space into an interface, facilitating the temporal and spatial expansion of information sharing.

In this context, we explore the integration of the Interspace concept and Safety2.0 into autonomous mobile robot systems that coexist and/or collaborate with humans. We investigate how expanding the temporal and spatial sharing of information among humans, objects/machines, and the environment through Interspace affects the simultaneous achievement of productivity and safety. Additionally, we assess the impact on well-being, including ANSHIN and satisfaction. This paper presents a comprehensive report on the results of these effects.

Keywords: Common Ground, Interspace, Factory Automation, Collaborative safety, Safety2.0, ANSHIN, Well-being, Collaborative robot, Service robot, Autonomous Mobile Robot

Tendency surveys of drone-related accidents and evaluation of the effectiveness of protective equipment

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Abstract. Introduction：The widespread use of UAS (Unmanned Aircraft System), commonly referred to as drones, has caused in drone-related personal injury accidents. When machines (drones) are used for work, management is necessary to ensure the safety of workers (employers) in terms of occupational safety needs. However, commercial drone instruction manuals are not sufficient in explaining what kind of risks are associated with drones and how to take countermeasures, making it difficult for users to conduct risk assessments and reduction. Therefore, this paper investigates drone-related accident situations and tendency to cause injury in order to provide basic information for users to conduct drone risk assessments. Furthermore, we provide information to ensure worker safety by clarifying the effectiveness of protective equipment through experiments in which a propeller collides with protective equipment.

Methods：To investigate the accident situation and injuries, we used accident cases extracted from data of NEISS, which is operated by the CPSC in the United States. They were extracted by searching the Narrative column for multiple key words related to drones and then classify them by the authors. In an experiment to evaluate the effectiveness of the protective equipment, cut-resistant gloves, eyewear, and helmets were struck by a rotating propeller.

Results：Among accidents that occurred between 2010 and 2022, 400 cases were extracted, and after reaching a peak (41 cases) in 2016, the number has been decreasing. 74 (18.5%) occurred while operating the drone, 48 (12%) occurred during preparation/tidying up/repair/adjustment, and 18 (4.5%) occurred during hand catch/launch. In addition, 37 (9.3%) were accidents such as falling while trying to retrieve a drone caught in a tree. When categorized by injury, 213 (53.3%) of the 400 cases were lacerations or amputations of fingers, 51 (16%) were lacerations of the arms, and 28 (7.8%) were lacerations of the face, including the eyes. 380 (95%) were released from the hospital after treatment/examination and were therefore presumed to have minor injuries.

Without cut-resistant gloves, the possibility of finger amputation is high when the propeller diameter is 15[in] or greater but wearing cut-resistant gloves compliant with EN388 and other standards reduces the possibility of amputation. However, when the propeller diameter exceeds 20[in], we observed cases of finger amputation/fracture even when wearing cut-resistant gloves. Eyewear compliant with standards such as ANSI Z87.1 with fixation straps has proven highly effective in reducing risk for propellers up to approximately 20[in] in diameter. However, we confirmed that eyewear without straps was damaged or fell off when a propeller hit the eyewear from the side even when the propeller was less than 20[in]. We have not identified any instances of a 20 [in] propeller penetrating the top of a helmet complying with EN 397.

Conclusions：Although the number of drone-related accidents is estimated to be decreasing, the potential for serious accidents, such as amputation of fingers and blindness, remains neglected. We confirmed that protective equipment such as gloves, eyewear, and helmets have a certain risk-reducing effect, but the negative impact of protective equipment on controlling performance is unknown. Considering the current situation where aircraft with propellers larger than the 20[in] used in the experiment are commercially available, it is necessary to consider more effective safety measures against drone-related injuries. In addition, the standards referenced in the collision tests are not standards that define the performance of protective equipment for drone collisions. Therefore, new evaluation methods and standards need to be developed to evaluate and develop protective equipment for drone collisions.

Keywords: Drone, UAS, Propeller, Risk Reduction, NEISS

Fusion robotics safety; the emergency management system for the remote handling robots of JET

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Abstract. The Joint European Torus (JET) is a large fusion experiment tokamak. Over the last 20 years of its operations, it has been remotely maintained with a telerobotic system – the JET remote handling system. The JET remote handling system comprises two 11-meter articulated robotic booms which can transfer robotic systems and tools in the heart of the JET machine for intricate operations. One such telerobotic tool, the Mascot 6 telemanipulator is a 14-axis local-remote telerobotic device that enables precise operations with high fidelity of positional and force feedback to the operator. Using this remote handling system, operators have performed over 35000 hours of operations inside the JET tokamak using over 350 tools for cutting, bolting, welding, grinding, inspecting, and cleaning the machine.

The JET remote handling system operates in a challenging environment; beryllium and tritium are present within its operational envelop as well as radiation from the materials activated during the operations of the JET tokamak.

The JET remote handling system is being upgraded to address obsolescence and reliability issues and to prepare the system for the next phase of remotely decommissioning the JET tokamak.

Here we present the new safety system for the JET remote handling system that ensures human operator safety across the entire system and during all project phases from development to decommissioning of the remote handling system. We describe the challenges of integrating to and updating a legacy safety system, the innovations afforded by new safety technologies, and the architectural and operational recommendations for large robotic systems which have an integrated human in the loop.

After describing the overall safety infrastructure, the risks from the remote handling system, the intended operations, and the safety objectives, we focus on two main safety technical challenges.

First, we describe the risk analysis and the full risk mitigation and engineering measures for the Mascot 6 telemanipulator that poses a constant risk to the human operator; telemanipulators are always on collaborative mode. We discuss the hazard identification and the safety functions that were designed, their implementation with new hardware, and the challenges and recommendations on implementing safety on telemanipulators. We frame this work with the recommendations of ISO 13849 and ISO TS 15066 and present how the new Mascot 6 safety system was designed according to these standards.

Second, we describe how an active zoning for the safety system was developed to adapt to the agile operation of the JET remote handling system without compromising safety. The physical rearrangement of the JET remote handling system within and between buildings means that different parts of the JET remote handling system need to be active at different times. The safety objectives and the identified risks from operations require integration between all working systems. We detail the operation requirements that lead to the need of an active zoning system, and we describe its design and implementation. We discuss the human factors considered and the human-interfaces created to aid with the understanding of the state of a complex and agile system by the operators. This includes the integration with non-safety control systems to aid in overall operability of the remote handling system by the operational team.

We conclude this work with a presentation of data from 1000 hours of operation post commissioning and present our findings from the early operational feedback. We note the recommendations on safety design for large telerobotic installations, and special consideration when working in hazardous environments with radiation and hazardous material.

Keywords: Telerobotics Safety, Multidisciplinary safety design, Risk Assessment for robots, Human Factors, Functional safety, Fusion

Review of possibilities in the EYE-TRACKING LAB for the safety of process control operators

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Abstract. To enhance the level and quality of safety in industrial automated systems, there exists a wide array of technological solutions and methods. One such promising technology in this field is EYE-Tracking LAB. It allows for the analysis of various risks, thereby contributing to their prevention. In this scientific article, new and potentially in-demand directions are discussed and an overview of existing solutions using EYE-Tracking to improve safety in the use of industrial automated systems is provided. The method for diagnosing the operator's attention and fatigue in working with large and complex automated control systems in various industrial sectors, such as petrochemicals and energy, is described. As of today, the EYE-Tracking LAB technology is actively employed in various fields. Additionally, it proves to be cost-effective and efficient in its application.

Keywords: EYE-TRACKING LAB., Process control., Technology.

RAS Safety Framework: A Digital Twin-Based Approach to Assurance of Complex Systems

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Abstract. There are several standards and regulations that aim to govern the safety of robotic and autonomous systems (RAS), especially where work is done collaboratively with a human. In response to these regulations, new approaches have been developed to maintain an acceptable level of risk in systems with novel human/robot interactions. These approaches apply technologies such as Digital Twins and Machine Learning in new ways to promote safety.

Current state of the art includes methodologies for creating safety cases for autonomous systems, process automation design and monitoring using digital twin, use of a digital twin to collect and process real-time data in safety critical systems, and assessment methodologies that provide structured arguments for reliability.

However, even with these advancements, there is a lack of information or guidance of how to bring these technologies and approaches together to present a clear and convincing argument about the safety of a particular industrial process or system that complies with the regulations.

In this paper, we tackle this challenge head-on, and present a novel RAS Safety Framework which is the first end-to-end Framework to

- Assist with the development of a system safety assurance argument (safety case) using a Digital Twin
- Provide a clear structure for identifying and addressing risks
- Develop the reasoning and provide supporting verification and validation evidence

The RAS Safety Framework consists of three major parts – the overall assurance process, the assurance argument (safety case) and the Rule-Based implementation in the Digital Twin . This Framework solves the problem of lack of RAS safety guidance by providing the structure and processes needed to bridge the gap between safety assurance, systems development, digital twins and industrial automation. In addition, the advantages of this approach, such as adaptability to dynamic risk data, are particularly observed in highly complex environments where a traditional approach to risk management would be limited.

To demonstrate its utility, the Framework was applied to an industrial case study with a collaborative welding process (CSI:COBOT). The process consists of a human putting a part on a shared workspace where it is moved by a UR10 robotic arm to a welder. The part is welded and returned to the shared workspace. This process has several known hazards such as burns from the welding and collision with the robotic arm.

Using the Framework we were able to explicitly define the context of the process, including entities and actions. A standard system safety risk assessment approach (STPA) was used to identify the potential hazards. The safety case was then developed with claims that each of the hazards were addressed – this included 'behavioural' hazards such as a collision hazard that only occurred if the human was in a particular area during a particular phase of the process. These rules were implemented and monitored in the Digital Twin.

As well as adhering to the requirements and recommendations in ISO 10218 and ISO 15066, using the Framework, we were able to identify a set of additional 'safety rules' that constrained the behaviour of the system during operation to prevent any emergent causes of the known hazards.

The key results of the case study were

- An end-to-end traceable safety risk assessment of the dynamic scenario
- A complete structured safety case with evidence to support each safety claim
- A Digital Twin with the capability to assess rule violations before running the process, and to monitor rules during operation
- An augmented reality visualisation of the safety of the process

Unlike many other approaches that consider just one aspect of risk, the RAS Safety Framework allows us to understand the behavioural hazards that arise during operation to a greater degree, and develop better mitigations thereby improving the overall safety of the system or process.

Another significant advancement of this approach over existing methods is that this end-to-end Safety Framework directly facilitates the development of a clear, structured safety case. It also allows safety claims to be substantiated with traceable verification and validation data from the Digital Twin, therefore improving the efficacy of communicating safety and risk information to regulators, system operators and other stakeholders.

Keywords: safety assurance, cobot safety, structured assurance case, digital twin, regulatory compliance

New approach to industrial security offers also potential savings

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Abstract. In a survey conducted by the IFA, the extent to which the networking of control systems in companies has already progressed was investigated. The focus was on the networking of devices which, if compromised, could injure or even kill people. A closer look revealed that a significant number of control systems are capable of injuring and killing employees if attackers manage to take over the respective control system via the Internet and control it maliciously.

The results of the study reflect the headlines in the news about current attacks on industrial control systems and show that networks in industrial environments urgently need to be designed more securely. This poses major challenges, especially for small and medium-sized companies, which often only have a very small IT team. The Industrial Security Laboratory at the Institute for Occupational Safety and Health has therefore developed a modular concept with which companies can make their production network significantly more secure with little effort.

An easy-to-implement concept shows how predictive maintenance can be safely implemented in an industrial environment. In addition, a model factory was set up to test a secure tunnel for industrial protocols. The tunnel is able to protect connections that have an extraordinarily high level of reliability thanks to the redundant use of WIFI and 5G. In future, it will be possible to remotely control construction machinery, for example, which is dependent on both a secure and reliable data connection.

The decisive factor for companies here is the practical feasibility and low resource consumption. Even embedded systems with low computing power are able to use the secure tunnel. In addition to the technical solutions, the concept is rounded off by organizational measures that guarantee rapid accessibility in the event of an IT security incident. A short film and an information platform were created for this purpose, with which all companies can create an emergency contact in just 5 minutes with which they can be reached immediately by authorities and security researchers worldwide.

Keywords: Industrial Security, Security, Safety, Industrial Control Systems, Controller, Security Management, Remote Access, Network, Sustainability

Design methods of safety for facilities considering productivity in collaborative workspace

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Abstract. In Japan, labor shortages are accelerating due to the decline in the working population. For this reason, collaborative robots and Autonomous Mobile Robot (AMR), which allow for collaborative operations with humans, are increasingly used to promote the automation of human work in the manufacturing field. So the current approach to the safety of machinery is not enough for facilities with cooperative work spaces, and new safety approaches are required.

According to the current safety approach, guards are used to isolate the hazard from the operator, to prevent the operator approaching hazard, or, when a worker approaches a hazard, safeguards are used to stop the hazard.

In the facility utilization, it is not possible to completely isolate the worker and the hazard in a cooperative workspace, so shutting down the hazard is the main protective measure.

However, if the task requires repeated safety function shutdowns, it is difficult to accept this type of facility from the user's side, even though safety can be ensured, because productivity becomes a problem. Therefore, the protective measures for facilities with collaborative workspaces should be designed considering productivity.

As integrator, we have been implementing validation of protective measures with consideration of productivity and have promoted the development of work environments based on risk communication with users.

Based on this experience, we introduce the concept of safety measures that take into account productivity in collaborative workspaces.

Keywords: collaborative workspace, safety and productivity, integrator

Tag and Knowledge-based Standards Documentation

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Abstract. The CE marking process is mandatory for machines in order to declare conformity with all harmonized safety standards and, thus, with the directives. The comprehensive identification of all relevant and applicable standards and laws is a major challenge, especially for smaller companies and start-ups with no previous experience in safety certification. Anecdotal experience shows that the inclusion of standards and laws in product development is often neglected and the gap between the product and legal requirements only becomes apparent late in the development process and may cause economic damage or inhibit innovation. The author believes that, in addition to a lack of knowledge about safety requirements, the main reasons for this are poor accessibility to the relevant standards and the fact that they are hidden behind paywalls, which is an additional economic hurdle where the relevance is not certain. Furthermore, the titles and keywords of such standards lack continuity and are used differently depending on their origin. In addition, the standards are often interdependent and the necessities and affiliations are not clear.

In this article, we present the concept of a tag-based description of a machine in conjunction with standards documentation to solve the aforementioned problems, in particular the identification of relevant standards in relation to the specific machine. The solution extends the first step of the risk assessment, the determination of the limits of the machine, by defining the domain, hazards and areas of application through tags. These tags have been developed in such a way that they can describe the machine unambiguously, but at the same time are general enough to keep the list reasonably short and not too specific. This results in a universal method of describing the machine and avoids synonyms. This same list of tags is also used to categorize and assign the tags according to domain, hazard and area of application for the standards. The relevant standards ultimately result from the combinations of the respective tags when determining the limits of the machine. This results in a dependency, and if the limits of the machine are changed, this is reflected in the relevant standards. In the standards documentation, on the other hand, references and quotations from other standards can be indicated. This allows further dependencies and affiliations to be investigated if required.

This tag and knowledge-based documentation makes it possible to identify the relevant standards for the specific machine and thus support small and medium-sized companies in particular with the safety certification of their machines. This approach also forms the basis for more dynamic approaches to safety and risk assessment, moving away from static, inflexible assumptions and towards dynamic and digital systems.

Keywords: safety of mobile robotic machines, standard identification, knowledge-based documentation

A tale of automation safety: Lessons learned from automotive to aviation and beyond

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Abstract. Industrial automation is increasing due to the potential to reduce costs, and expectations to increase productivity, efficiency, agility, safety. The latest developments are fueled by technological leaps, such as AI advancements for robotic automation, metaverse, machine vision and “humanlike” machine perception, to name a few. However, the generic narrative has often been that the workers should adapt to the automation.

From an organizational factors perspective, it is critical to design and implement automation solutions in a way that allows the people in organizations – from shop floor workers to top managers - to make sense of the underlying conditions and make decisions that control the potentially unsafe and dynamic conditions to prevent risks from actualizing. Organizational factors, such as decision-making, communication, incentives systems, competence development and training, leadership, management and culture for safety, as well as political, social, economic and regulatory context all play an important role for creating conditions for safe automation. Previous research in the context of offshore drilling automation indicated that organizational factors are influenced by automation systems, and they also influence the way in which these systems are applied in a specific organizational setting (Gressgård et al., 2013).

This paper tells a tale of automation safety, bringing in insights, lessons learned and historical accounts from automotive industry to aviation and beyond. It advances our understanding the organizational factors and the broader institutional factors, business and operational environment by crystalizing specific lessons learned from the Boeing 737 MAX crashes and linking them to historical accounts for developing regulatory foundations for automotive safety. Latent deficiencies in these factors or potential system vulnerabilities have been observed decades ago in the Boeing’s case but their cumulative effect on safety have not been timely and effectively addressed. Research method is scoping review of public sources and publications. The value of cross-industry learning is emphasized: although different safety-critical industrial domains have specific standards, requirements and regulatory context, there are similarities, which allow for transferability of lessons learned to support safety oversight and overall safe operations in complex sociotechnical industrial settings.

In the aviation sector, following the Boeing 737 MAX crashes in 2018 and 2019, working groups have been set up by authorities in the nuclear industry to gather and distil valuable lessons learned. For example, the Canadian Nuclear Safety Commission (CNSC) and the Radiation and Nuclear Safety

Authority in Finland (STUK) have analysed recommendations arising from these crashes to identify potential improvements that could be applicable to the nuclear energy industry.

Broader applicability of the regulatory and organizational lessons learned related to automation design and implementation is relevant also for other industrial domains, such as manufacturing. Recent organizational studies on the Boeing 737 MAX accidents have shed light on the powerful influence of institutional factors on organizational culture and decision making (Gotcheva and Ylönen, 2021), the role of organizational failures such as deficiencies in oversight (Viitanen et al., 2024).

Boeing's Maneuvering Characteristics Augmentation System (MCAS) has gathered significant attention in various reports and studies following the accidents. MCAS is an automation system that has a significant impact on pilot operations and has a direct impact on aircraft control. This software system was designed in relation to hardware change in the Boeing's aircraft – the changed size and position of the engine to increase fuel efficiency changed the aerodynamics of the aircraft, which required additional means for adjustment without pilot's intervention through the MCAS software. In the design phase, this system was considered to have a low safety impact, of which users would not need to undergo additional simulator training. However, MCAS, as any automation system, had been designed and implemented based on certain cultural assumptions, decisions have been made and approved under established leadership and within defined resources, and affected by the broader organizational set up and the institutional and regulatory environments.

The paper concludes by summarizing the key insights and emphasizing the power of learning by storytelling, and the importance of by knowing the past to shape the future of safe automation.

Keywords: automation, organizational factors, institutional factors, aviation, storytelling