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Collaborative Robotics Research: Subiko Project

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Abstract

Aim of the research is to present the possibilities of applying cooperative robots during the process of automotive metalworking. The study is focusing at the Hungarian medium enterprise sector. Artificial Intelligence and special cobot safety systems - modified by human behavior - are used to demonstrate how production techniques are used at a Hungarian medium enterprise to optimize their processes. The main problem is with flexibility in the automotive metalworking manufacturing industry, such as production line switchover and the processing period. The product price is therefore determined by the competition, and the only way to increase profit is to reduce production and distribution costs. This means that managing and operating the organization and manufacturing in an efficient manner is necessary. One of the success factors is the flexibility of manufacturing by robotization. The proposal solution by this study is a low-load universal cobot system with innovative security solutions for improve the flexibility of manufacturing in an automotive metalworking manufacturing company. This instance is based on a real case study problem in an automotive metalworking manufacturing company.

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Keywords: Cooperative robots; Human-robot interaction; Safety-critical systems; R&D; Automotive metalworking.

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1. Introduction

The development and application of collaborative robots is progressing more and more dynamically. This is due to the fact that such robots can be flexibly integrated into a workflow where robots and humans are required to work in a common work space, with well-defined protection zones. In these workflows, the user - the human - controls the pre-recorded work of the cooperative robot. In many cases, the robot performs the stressful and monotonous part of the task in the collaboration. This technology creates a new kind of risk and requires updating and developing new systems of requirements, laws and standards. [1][2][3][4][5]

1.1. Application of Collaborative Robots

In a manufacturing process (e.g. powertrain assembly [6]) combined with a general robot, the robots are located in a space enclosed by protective fences and sensors and are physically separated from humans. The new goal is to secure a common working space for cobot and man.

1.2. Perception of Robot Danger

In any case, it is up to the employer to decide whether the collaborative robot is a dangerous work tool, there is currently no legal requirement for this, but guidance can be provided by the Hungarian Labour Protection Act. [7] It is necessary to consider the maximum force [8] (motion control: desired forces/torques [9]) that a cobot can exert on a human in the event of a collision.

1.3. Legislative background to the use of robots

Collaborative robots have a very short history (this research topic also has regulatory dilemmas [10]), so there are few international standards adapted to the Hungarian language. Therefore, international standards are applicable when integrating robots into the workflow. The standards currently known and used are as follows (see Table 1):

1.4. Terms and definitions

System Engineering: "At NASA, "systems engineering" is defined as a methodical, multi-disciplinary approach for the design, realization, technical management, operations, and retirement of a system. A "system" is the combination of elements that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose; that is, all things required to produce system-level results." [11]

Collaborative workspace: "Collaborative workspace space within the operating space where the robot system (including the workpiece) and a human can perform tasks concurrently during production operation"[12]

Collaborative mode: The state in which the robot is working with the robot operator in the collaborative workspace. [12]

Safety distance: the minimum allowable distance between the robot and the operator. [12]

Fail operational: systems are able to operate even if their control system fails. [13]

Fail-safe: systems mean that in the event of a system failure, the system becomes safe preventing the occurrence of more serious problems. [13]

2. Collaboration Levels for Human-Robot Cooperation

There are multiple levels of interaction between industrial robots and their operator. In manual handover mode, the robot communicates directly with the operator in the handover window, where the robot has reduced speed and a working space with inhibited sensors. Through the window, the operator can safely change workpieces during automatic operation. A more advanced form of this is the contact window when the robot stops at the contact window and the operator can manually move it out of the workspace delimited by the window. This is called Hold-

To-Run control mode. In another mode of application, the robot first decreases its speed in proportion to the distance between the operator and the robot, and then stops when a person enters a restricted zone of his work area. The robot can be restarted if the forbidden zone is empty. In the case of the most advanced cooperative setup, the operator can move the robot with manual control, in a specific common work space, on a specific path. Previously, robot-based technologies (such as robotic cells) had been used to separate human and machine work from one another, while recent innovations aim to break these boundaries and create cooperative and collaborative operations.

Table 1. The important standards for Research and Development of Cobots (own edit)

ISO/TS 15066:2016	Robots and robotic devices	Collaborative robots
ISO 10218-1:2011		Safety requirements for industrial robots - Part 1: Robots
ISO 10218-2:2011		Safety requirements for industrial robots - Part 2: Robot systems and integration
IEC 61508-1:2010	Functional safety of electrical/electronic/programmable electronic safety-related systems	Part 1: General requirements
IEC 61508-2:2010		Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems
IEC 61508-3:2010		Part 3: Software requirements
IEC 61508-4:2010		Part 4: Definitions and abbreviations
IEC 61508-5:2010		Part 5: Examples of methods for the determination of safety integrity levels
IEC 61508-6:2010		Part 6: Guidelines on the application of IEC 61508-2 and IEC 61508-3
IEC 61508-7:2010		Part 7: Overview of techniques and measures
ISO 12100:2010	Safety of machinery	General principles for design - Risk assessment and risk reduction
ISO 13850:2015		Emergency stop function - Principles for design
ISO 13855:2010		Positioning of safeguards with respect to the approach speeds of parts of the human body
ISO 13482:2014	Robots and robotic devices	Safety requirements for personal care robots
ISO 8373:2012		Vocabulary
IEC 62061:2005	Safety of machinery	Functional safety of safety-related electrical, electronic and programmable electronic control systems
ISO 13849-1:2015		Safety-related parts of control systems - Part 1: General principles for design
ISO 13849-2:2012		Safety-related parts of control systems - Part 2: Validation
IEC 62443-4-1:2018	Security for industrial automation and control systems	Part 4-1: Secure product development lifecycle requirements
IEC 62443-2-1:2010	Industrial communication networks - Network and system security	Part 2-1: Establishing an industrial automation and control system security program
ISO/IEC/IEEE 29148:2011	Systems and software engineering -- Life cycle processes	Requirements engineering
IEC 60870-5:2018	Telecontrol equipment and systems	Part 5: Transmission protocols - all parts
ISO 21500:2012	Guidance on project management	Guidance on project management

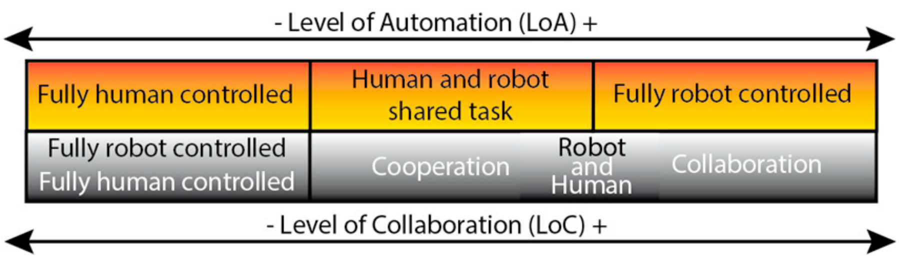

Fig. 1. Levels of Collaboration [14].

3. Robot security features and risk reduction

The following safety functions support human - machine interaction. The robot movement can be stopped before the operator enters the collaborative space. As a general rule, while the operator is not in the collaborative space, the robot is not working collaboratively. When the operator enters the safety zone of the robot, the robot first reduces its operation and then stops it. The robot starts working at maximum speed when the operator leaves the safety zone. With manual control, the safety zone is flexible and depends on the speed of the job and the task that is manually controlled by the operator. When implementing speed and distance monitoring, the cobot and operator can move in the common area at the same time. Depending on the safety zone, the cobot reduces, stops or increases its speed in response to the operator's reactions. After stopping, the cobot can restart automatically or manually as instructed by the operator. The robotic arms are equipped with torque and force limits [8] to prevent the operator from accidentally striking the front. [15]

Using collaborative robots reduces the risk to cause injuries to operators. An important aspect when designing collaborative robots is the exterior design. This plays a big role in reducing risks (e.g. the edges are always rounded). These robots can be mobilized and require little space. They are suitable for the operator and the robot to work side by side without physical fencing. Communication links are compact in design, which means that wiring harnesses are in most cases hidden. Collaborative robots allow the person working with them not to get tired of monotonous work. This is due to the advanced sensor system of robots, which always gives priority to safety. [15] [16]

4. The SUBIKO® research and development project goals

The goal of the development is to create a cooperative robotic system (integration of multiple cooperative robotic arms and their environment / cooperative and non-cooperative machines and people). The system should meet that meets the increased safety requirements, which reduces the risk of accidents between machines and people, while maximizing the availability, reliability and operational, migration costs Maintainability of the system [6] is expected to be low not only in mass production, but also in smaller varied series, flexibly without costly switching through online risk analysis (used techniques: machine learning, deep learning [17] [18]) and determinable AI (Artificial Intelligence). [19] [20] [21] [22] That means the project software elements Robot Interconnect Distributed Scheduler and Robot Supervisor.

During development, the technologies required by the standards are applicable. If there are no such standards in the particular field, the applicability of the technology for the development purpose is proven by experiments, measurements and simulation. When designing parts of a cobot system, we carry out a risk analysis as required by the standards, which we use to categorize which items fall into a risk category. For security-critical system components, we apply security-critical hardware and software architecture and development methodology. [23] During development, we determine the required safety integrity level (SIL) for each subsystem. The feature of the cooperative robotics system that makes human interaction safer is the image processing system (human, obstacle point cloud, workpiece positioning and orientation. human nervous system perception, robotic environment recognition) and the services based on it greatly increase the flexible usability of the cobots. It is necessary to determine which procedures can be integrated into the cobot system, which can be expanded later, and users can upload their own unique image processing procedure to an image processing routine. [24]

Customized manufacturing of smaller varied series requires a high degree of flexibility and is expected to play a role in the process. Maintaining safety when in the workplace requires physical measures and requires lengthy risk analysis. Safe handling of such complexity is difficult due to the size of the large problem space. Full testing is not possible. A general principle in achieving security is that complexity should be kept low. This is combined with flexible operational needs, which are mutually exclusive. One solution to this is the systematic problem resolution, in which we break down complex problems into smaller parts and then solve them by repeating simple rules several times. During the project it should be examined whether the security tasks identified during the design of the cobot system support the expected production flexibility with such a systematic breakdown. The security mode required by the robot system depends on the environment. According to our preliminary research, we implement two main security approaches (reliability systems) in integrating Fails-safe and Fail Operational in the operation of the cobot.

[3] The conflicting implementation of these two modes of operation does not allow the creation of a general purpose cobot system. When designing reliability, we place great emphasis on integrating cyber security and integrating it into the development process. To ensure the flexibility of the cobot system, we use AI (Artificial Intelligence). We intend to prove the applicability of AIs in task-specific security environments through research and experimentation during the project. The subprojects aim to increase security in a flexible layout and application environment. By implementing a cobot system we enable the top-down decomposition of tasks. If multiple robotic arms or people, and other equipment are required to work together on a job, the tasks are rescheduled online according to the current operating conditions. The system is able to perform risk analyses necessary for its operation, and is also able to detect potential hazards, alongside with their expected probability and the expected extent of damage event. By comparing alternatives, the system has the capability of making predictions during operation to assist itself. These security measures created by the cobot system during operation are implemented by the system. Based on the self-generated emergency scenario, fail-safe or fail-operational mode will be implemented. Figure 2 illustrates the security operation of a cooperative robot. [24]

5. Architecture and Systems Engineering Models and Methods to Manage Complex Systems

The following section details the adaptation of Scrum v Agile development methodologies in cobot system development.

Scrum is a methodological framework used in software development. With this method, companies can easily develop and support a product in a complex and dynamic environment [25]. Scrum is the answer to the rapid evolution of technology and the rapid change in customer needs. The starting point of the method is experience. We try and learn from our experiences and decide how to continue to develop. Scrum teams consist of 4-5 people in the project. These teams control themselves. Team members work on a step-by-step basis. At specific stages, a new product / component, a component or function that can be identified as an element or an improved version of an earlier result product is created. These races are called sprints. The methodology will allow for continuous and realistic development on a timely basis. [26] [27]

Splitting work into sprints is ideal because it allows the team to plan the workflow more realistically, as they can see more precisely what should be done and how much time it will take. Therefore, the design process will be much more predictable. Developments in short periods are also better for risk management. Shorter sub-tasks do not require lengthy comprehensive planning and complex risk analysis at the same time. The results achieved by the teams in the short term become visible to those involved in the development and to the customer. Obstacles to the development process can also be tackled more quickly and easily. Short time intervals allow for more transparency in team work and project management to intervene quickly for a project if needed. At the end of each sprint, the results of the development can be presented to the customer. The project becomes more transparent, so the customer can provide direct feedback that the team can use in the next sprint. This is how we develop the cobot system as a product to meet the needs of the customer. [26] [27]

In the Agile methodology, individual and personal communication is more important than processes and tools, working software is more important than comprehensive documentation, cooperation with the customer is more important than contract negotiation, and responding to change is more important than rigid follow-up of plans. Twelve principles have been established in the Agile methodology. The Agile mindset can also be useful in development. The point of introducing agile methodology is to make larger projects more flexible and responsive to change. Larger projects are less flexible. Projects typically use the waterfall model. In this case, you first have to go through certain phases, which can be lengthy, thus making development work slow. Agile methodology changes this. [28]

What is the difference between Scrum and Agile methodologies?

The idea behind Agile is that a project that wants to "survive" must be flexible and adaptable to change. Development projects must be flexible enough to adapt to new technologies and changing customer needs.

An Agile mindset allows you to return flexibility to your project and react quickly to change. In an Agile developer work environment, employees need to share knowledge, be creative, and find the solution themselves. The initiative is no longer a task for leaders but for researchers and developers in the field.

How does Agile work in practice?

In a traditional work setting, we try to rule out change: we make a plan and try to stick to it as much as possible. The starting point in agile thinking is that plans can change. It is not always possible to follow the same plan from start to finish. The development goal is clear, but the path to it can change. Agile work is a never-ending uninterrupted process of improvement. [29] [28]

When a cobot is developed, using agile methodology with scrum is strongly proposed. The development without agile and scrum, but with the V model or waterfall (for example) would take much more time. It is very likely that due to the long development time, the market or parameters will change. If the requirements are changing the cobot needs to be modified accordingly. A simple V model or a waterfall would not be able to follow without starting the design and development from the beginning and therefore losing development time.

Scrum can easily follow the changes between the release cycles of the project and adopt to the new requirement minimizing the time cost. As mentioned before, the key feature in these methodologies is the quick tracking of changes which makes them perfect for cobot system development.

6. Results and Discussion

The reviewed literature and the examined cobots are very different from the cobot system we have designed. As part of the project, Robot Interconnect Distributed Scheduler and Robot Supervisor will carry out online risk analysis using artificial intelligence. This increases the availability, speed and security of the robots. Cobots must behave in a fail-safe or fail-operational manner, depending on the application. Current cobots use only one of these methodologies; most operate in a fail-safe manner. Fail-operational mode mostly a requirement for robots applied in the medical field. The difference between the two operating modes can be decided on the basis of risk analysis. When stopping the cobot involves more risk than further running it, the fail-operational mode is expected. If stopping the cobot is more likely to cause accidents (or material damage) then fail-safe operation is expected. Illustratively, the aircraft's on-board systems cannot be stopped, because it would cause the aircraft to be uncontrollable

The typical behaviour of the two modes of operation for sensor failure is as follows. The fail-safe sensor switches to safety mode in the event of an error. Either it stops immediately, or the system moves to the designated safety position at a safe speed. Sensor duplication is used to detect sporadic error by comparison. In the event of a fail-operational failure the sensor switches to redundant or secondary (based on data from other sensors) detection mode and continues to work in a safe mode (by reducing risks as much as necessary and possible / eg engine speed limitation). The project's AI management system and extended sensor network will allow fail-safe and fail-operational modes. This requires online and real-time risk analysis. The project will develop an AI network capable of risk analysis and determination of the output of AI.

The schematic HL (High Level) decision process can be interpreted as a closed chain. The system makes the decision based on the data collected by the senor network. This decision is split because it can affect more robots (distributed decision making). [30] [31] Therefore, the decision has global and local levels. Both can make a security decision, but local is a priority. The local may decide to accept the global security authorization decision. But this decision can only be for a short period of validity and the current level of perceived worst-case risk should not exceed a predetermined level of risk.

The Control module performs a risk analysis and, after making a decision, re-verifies the decision risk before making a decision. After the outage, the system re-analyses the risk, waiting for the time constant of the system to qualify the previous decision. The rating is shaped by two factors. The decision includes known and predicted data. The rating is possible if the predicted data match. If the prediction was unsuccessful, it will be stored and will later improve its own prediction model. The robot arm can make its own decisions, but it can only perform the functions according to the standard ISO / TS 15066 standard.

Multiple structured or teaching AIs perform the same task, and then a statistic-based comparator chooses the right decision. Then, we compare the AI decisions. All inputs and decisions, and also the consequences are stored per AI, thus building a problem space-decision-efficiency database per AI. The system then applies a weighting to the decisions and carries out a risk analysis for each decision. The internal schematic of Control is as follows. The sensor performs a risk analysis based on network data, then actualises the system model and makes a decision. The model tests the decision. Based on the model, it predicts the new condition and assesses its risk. If appropriate, the decision will be ran in the rule database. If appropriate, the decision will be outputted; if not, then restrictions will follow based on the rules. Automatic production layout recognition: with the help of unified messaging and object-oriented communication, the system is able to find and communicate with ring-connected equipment. If the system is in reconnaissance mode, the devices will move safely one by one and the system will use its sensors to determine where they are moving. In this way, in addition to detecting the logical system, it is capable of physical assessment and interconnecting the two. This will automatically record the production layout. The likelihood of image recognition uncertainty is complemented by a risk assessment procedure that judges the results of several different methods of image processing based on the robot's environment and operating condition. If there are several risk assessment options at system startup or when the environment changes dramatically, the system will use the one with the highest risk value. The system continually calibrates itself to assess the risk best suited to the environment.

7. Conclusion

The coordination of the two non-cooperative management systems (Fail-Safe, Fail-Operational) can be achieved through online risk assessment We can create additional security information for ancillary systems (which is required for risk analysis), and more detailed knowledge of the environment and support for automated task breakdown and execution. By combining fail-safe and fail-operational tasks with current scientific knowledge, robotic-controlled and human-based work sets up efficient workflow based on pre-designed data that eliminates the risk of human and technical failure where one operating mode would not have been enough and it is only discovered after the incident that the other operating mode could have avoided this accident. Understanding the scientific principles or relationships to drive forward this project overcomes the professional preconceived notion of how a previously unmatched security technology approach can improve efficiency in the manufacturing process and facilitate human-robot collaboration. Choosing between Fail-Safe and Fail-Operational may present a risk analysis for the scientific uncertainty that hinders the achievement of the set goals. A new concept to eliminate scientific uncertainty could be the development of a cooperative robotic system that meets increased security requirements, a project that can be deployed more rapidly and provides for faster reprogramming to increase the overall security of cobots, analyse human behaviour, perform automated cooperative tasks, and create security artificial intelligence.

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