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DOCTORAL (PhD) THESIS FOR HOME DEFENSE

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Safe welder robot application in the defence industry

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DOCTORAL SCHOOL ON SAFETY AND SECURITY SCIENCES

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CONTENTS

Declaration

I, Abdallah Kafi, hereby affirm that the research presented in this doctoral dissertation is solely my own work. The reference section meticulously documents all sources utilized in the composition of this scholarly work. Furthermore, I assert that this dissertation is an authentic piece of academic writing and has not been previously submitted, either partially or in its entirety, for the fulfilment of any other academic qualification. This PhD dissertation is submitted to the Doctoral School on Safety and Security Sciences of Óbuda University in fulfilment of the requirements for the Doctor of Philosophy degree award.

Budapest, 19th March 2024

Abdallah Kafi (Ph.D. Candidate)

INTRODUCTION

I did my Master's studies at the Bánki Donát Faculty of Mechanical and Safety Engineering of Óbuda University, majoring in mechatronics, where I studied the programming of welding robots. During my studies, I learned about welding robots' operation, programming and safety rules. The industry increasingly demands esthetic and high-quality welded joints, which robots can provide.

1.1 Welding

Welding is a critical process in the defence industry, where the reliability and integrity of components and structures are of substantial importance. The defence industry demands high-quality welding to ensure the safety, durability, and performance of military equipment and vehicles. The following welding processes have key priority in the defence industry:

- Armoured Vehicles: Tanks and Personnel Carriers: Welding is used extensively in the construction of armoured vehicles, ensuring that the joints between armoured plates are strong and secure. This helps in protecting the vehicle and its occupants from ballistic threats and explosions.
- Naval Vessels: Warships and Submarines: Welding is crucial in shipbuilding for the construction of hulls, decks, and superstructures. The integrity of these welds is essential for the vessel's performance and survivability in combat situations.
- Aircraft: Fighter Jets and Helicopters: Precision welding is required for the manufacturing of the airframes and critical components. Lightweight and strong materials like titanium and aluminium alloys are commonly used, requiring specialized welding techniques.
- Weapons and Ammunition: Artillery and Small Arms: Welding is used in the manufacturing of weapons systems, ensuring the durability and precision of barrels, frames, and other components.

Several welding techniques are employed in the defence industry, each selected based on the material, application, and required performance:

- Gas Tungsten Arc Welding (GTAW/TIG): Known for producing high-quality, precise welds, GTAW is often used for critical components where precision is paramount.

- Gas Metal Arc Welding (GMAW/MIG): This technique is widely used for its speed and efficiency, suitable for welding various metals used in military applications.
- Shielded Metal Arc Welding (SMAW/Stick): SMAW is commonly used in field repairs and construction due to its versatility and simplicity.
- Laser Welding: Employed for its ability to produce clean and precise welds with minimal heat distortion, laser welding is ideal for sensitive components and advanced materials.
- Friction Stir Welding (FSW): Used for joining aluminium and other non-ferrous metals, FSW is beneficial for its ability to produce strong, defect-free joints.

1.2 Robotics

The idea of robots or automated machines has a long history. Ancient Greek texts talk about Talos, the gigantic brass automaton, protecting Crete and Europe from pirates and invaders by walking three times around the island daily and throwing boulders at the approaching ships [1].

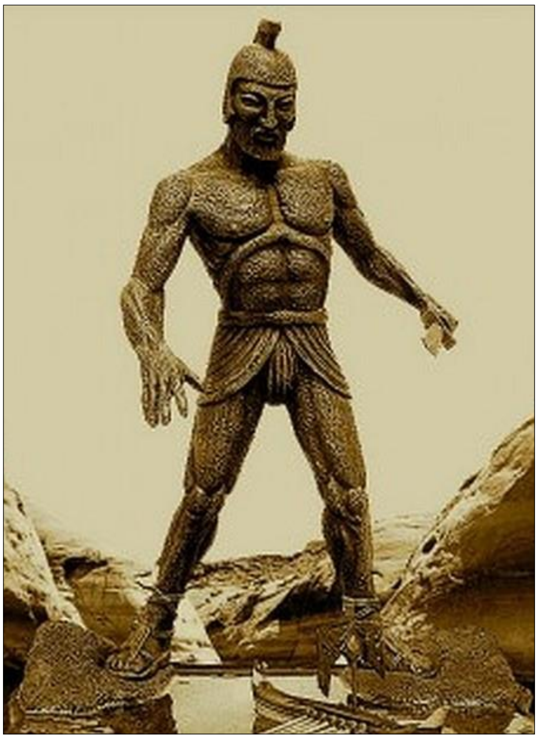


Figure 1 Talos, the gian robot of Hellas [1].

The ancient pieces (77–100 BC.) of a mechanical calculator, found under the sea, also prove humans have long been able to construct automatic machines. for example, the organs and water clocks of Ctesibus (270. BC.) and other mechanical devices we have used in robotics. Heron, the physicist and engineer, created an automatic mobile theatre. Heron and Philon even wrote books about automation and the basics of robotics.

Leonardo Da Vinci created a multitude of mechanical constructions in the Renaissance era. One of his most important creations was the mechanical lion (Figure 2.) [2].

Figure 2 Leonardo Da Vinci's Mechanical Lion [2]

The mechanical calculator of Blaise Pascal was a significant advancement in mechanical devices. This very useful machine was called Pascaline, although only 50 copies were ever created.

Mechanical devices built in the 18th century could be seen as primitive robots, these were mainly made for entertainment. for example, the likes of the Swiss watchmaker, Pierre Jaquet- Droz's humanoid robots or Jacques de Vaucanson's robot duck.

The first industrially feasible robot was named Unimate and it was created by George Charles Devol in 1954. A few years later Devol and his companion Joseph F. Engelberger founded their own company, the „Unimation Inc." [3] was born. This is the point where the science of robotics started to form.

2 GOALS OF THE RESEARCH

I recognised that the use of welding robots is a specialised field where many hazards arise. In many cases, the productivity and mobility of robots are hampered by barriers and curtains used to protect people working near the robot. Today, military production is growing. Accuracy, productivity and repeatability are key factors in military production. The use of robots in this area is therefore also growing rapidly. Collaborative robot applications are widely increasing in industrial applications. In the welding process, the robot application area is continuously growing. Manual welding is professional but really hard physical work while replacing it with collaborative robots can be a big advance for the industry. The collaborative robots application in the welding tasks is not solved yet.

Fusion welding is a professional work when which metal melts at high temperatures and the melted metal establishes a metallic cohesion joint [4] [5]. This process is widely used in a great number of tasks for metal manufacturing. The base of the heat source during the fusion welding process can determine several dangers. Labour safety requirements the supporting of human welder safety and health by the minimization of dangers. Even the ergonomic manual welding is almost impossible, labour safety tries to highlight the solution to prevent accidents and health damage [6].

In this research, I wanted to analyze a risk assessment of the dangers for humans in the welding workplace. On the base of the results determine the danger zones of the collaborative welder robot workplace on the base of the danger level and kind.

The automatization of welding in addition to preserving the health of the collaborative workers is a goal of our age. The results of this research want to support solving the actual and important questions of these industrial areas.

In the case of arc welding, UV radiation is an inevitable source of danger. For this reason, protective equipment is currently defined, for example: covering skin surfaces with clothing or welding masks, shields or goggles. This protective equipment has been in use for many years and mainly focuses on masking and protecting only the immediate wearer from UV light. In the welding workshop, the welding workplaces are separated by curtains and screens, thus protecting the other welders and workers. In a collaborative welding workshop, the human welders and the welder robots are working together at the same time. Increasing productivity and letting the robot move between workplaces without barriers requires a curtain-free area. The safety of human welders is a key point of the workplace. In the collaborative welder, the workshop has required the minimization of the robot welder-affected risk. This concept can be implemented using a virtual curtain.

The virtual curtain is the boundary of the danger zone that the system prevents from being crossed. The virtual border should be determined based on human exposure to UV radiation. Outside of the virtual curtain, people can move without danger and without safety equipment.

3 HYPOTHESIS

1st Hypothesis

The danger zone can be determined by the most dangerous effect of the welding in the case of robot GMAW.

Welding can have harmful effects on human health. These effects are of varying degrees of danger. The dangers can be interpreted within a given range. With a risk analysis and risk assessment of the welding technology, we can identify the most dangerous effects which can cause the greatest potential health damage.

2nd Hypothesis

The unhealthy UV level needs to be the base of the danger zone determination.

In welding technology and robot applications, it can be assumed based on practical and literature data that the greatest danger is caused by UV radiation at the biggest range.

3rd Hypothesis

It needs to determine the danger zone diameter on the base of the welding parameters (power, welding speed and shielding gas) in the case of GMAW

Welding parameters influence the strength of the effects that occur during welding, this is true for smoke formation, thermal expansion and spattering. It can be assumed that the strength of the UV radiation generated also depends on the welding parameters. Therefore, if the value of UV radiation depends on the welding parameters, the range can be determined by knowing these parameters.

4th Hypothesis

To ensure the safety of the welding robot workplace it needs to define different danger level zones around the welding.

The hazard of the effects of welding can vary at the same distance, so it may be useful to define different hazard zones to protect the health of workers in the welding environment.

5th Hypothesis

Collaborative robots can be used without physical barriers only when the danger zone is defined and the people are held out.

Welding often has to be done on large pieces, in which case several welders work together. The integration of a welding robot may be necessary to ensure safety. Traditional curtains and fences cannot be used for these welding tasks, so other ways of working safely must be found.

4 METHODS OF THE RESEARCH

Research methodology refers to the systematic approach used to conduct research and involves the selection of research methods, tools, and techniques to gather and analyze data. It encompasses the entire process of designing a study, from identifying a research problem to drawing conclusions based on the collected data. Here are the key components of the research methodology:

4.1 Research Design

Research design is the framework for collecting and analyzing data. It can be broadly categorized into three types [7]:

- Exploratory Research: Used to explore a problem or a new area where little information is available. Methods include literature reviews, interviews, and case studies.
- Descriptive Research: Aimed at describing the characteristics of a population or phenomenon. Methods include surveys, observations, and longitudinal studies.
- Causal Research: Focuses on determining the cause-and-effect relationships between variables. Methods include experiments and quasi-experiments.

During my research work, I used the exploratory and the casual research design because the researched area is a special aspect of the welding health effect investigation. I made several literature reviews as exploratory research. Also, I did casual research because I did several experiments.

4.2 Research Methods

The specific techniques used to collect data. They can be qualitative, quantitative, or mixed methods [8]:

- Qualitative Methods: Involves non-numerical data to understand concepts, opinions, or experiences. Methods include interviews, focus groups, and content analysis.
- Quantitative Methods: Involves numerical data to quantify variables and analyze statistical relationships. Methods include surveys, experiments, and secondary data analysis.
- Mixed Methods: Combines both qualitative and quantitative approaches to provide a comprehensive understanding of the research problem.

The applied research method was the mixed method because I combined the qualitative and quantitative methods too.

4.3 Sampling Techniques

The process of selecting a subset of individuals from a population to represent the entire population. Common sampling techniques include [9]:

- Probability Sampling: Every member of the population has a known and equal chance of being selected. Examples include simple random sampling, stratified sampling, and cluster sampling.
- Non-Probability Sampling: Not all members have a chance of being selected, often used in exploratory research. Examples include convenience sampling, judgmental sampling, and snowball sampling.

The sampling technique was non-probability sampling. The experiment was made on the base of the literature-suggested technique.

4.4 Data Collection Methods

The techniques used to gather data from the research subjects. Methods vary based on the research design and objectives [8] [9]:

- Surveys and Questionnaires: Structured tools with predefined questions are used to collect quantitative data from a large sample.
- Interviews: These can be structured, semi-structured, or unstructured, and used to gather in-depth qualitative data.
- Observations: Involves systematically recording behaviour or events as they occur naturally.
- Experiments: Controlled studies where variables are manipulated to observe their effect on other variables.

The data collection method was the experiment-based method. I did several experiments to earn data.

4.5 Data Analysis

The process of organizing, interpreting, and drawing conclusions from the collected data. Methods depend on the nature of the data [9]:

- Qualitative Analysis: Involves coding and thematic analysis to identify patterns and insights. Techniques include narrative analysis and grounded theory.
- Quantitative Analysis: Involves statistical techniques to test hypotheses and examine relationships. Methods include descriptive statistics, inferential statistics, and regression analysis.

I used quantitative analysis to test my hypotheses and find relationships.

4.6 Validity and Reliability

Ensuring the accuracy and consistency of the research findings [9]:

- Validity: Refers to the extent to which the research measures what it is intended to measure. Types include internal validity, external validity, and construct validity.
- Reliability: Refers to the consistency of the measurement over time. High reliability means that the results are repeatable under similar conditions.

It was important during my research to do repeatable tests to verify the results of my measurements

4.7 Summary of the Research Methodology

I used the introduced methods and techniques because is a critical aspect of conducting robust and credible research. The research design was exploratory and the casual justified by the special researched area.

I made several literature reviews as exploratory research. Also, I did casual research because I did several experiments. The applied research method was the mixed method because I combined the qualitative and quantitative methods too. The sampling technique was non-probability sampling. The experiment was made on the base of the literature-suggested technique. The data collection method was the experiment-based method. I did several experiments to earn data o n the base of the reviewed literature references.

I used quantitative analysis to verify my hypotheses and find relationships. It was important during my research to do repeatable tests to verify the results of my measurements and to conclude my claims.

I obtain reliable and valid results by carefully selecting and applying appropriate research designs and methods.

5 REVIEW OF THE ROBOTICS IN THE INDUSTRIAL AREA

5.1 Safety requirements of industrial robots

The name „robot” originates from Karel Čapek Czechoslovakian writer. He created the word from the abbreviation Rossum’s Universal Robots (R.U.R.) (1921.). Since then, common and professional terminology has adopted this designation [10].

Later, the three laws of robotics were created in (1942) by Isaac Asimov:

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.

2. A robot must obey the orders given to it by human beings except where such orders would conflict with the First Law.

3. A robot must protect its existence as long as such protection does not conflict with the First or Second Laws.

The cornerstones of the science of robotics are these laws. Robotics is an interdisciplinary field of engineering sciences, containing the fields of mechanical engineering, electrical engineering, and computing studies, and to this list has been added informatics science because the robot is required to receive instruction and programming from afar.

In the case of industrial robot systems, there is no limit of force or velocity because of increased performance. Industrial robots work automatically, can be programmed and can utilize multi-axis movement.

With the implementation of industrial robots, new ergonomic and safety regulations became necessary, as a human working alongside a robot, has to operate within abnormal work conditions. During industrial processes, the human workforce’s safe working condition has to be created. furthermore, the robot also has to be protected as machine abuse is well known to have been prevalent throughout the Industrial Revolution, when people saw machines as a threat to their jobs, and destroyed industrial machines. Of course, damage can occur without ill will – by the lack of knowledge of the operations, or by accident. The operator has to be a well-trained professional, in many cases an engineer, with wide-scale knowledge of the robot’s operation, programming, and applicable safety regulations.

5.2 Automatization and robots in welding

Welding is an industrial process that has a strong history. for a long time, manual welding was the only option. The quality of the welded joint was dependent on the welder's skill. Manual welding inflicted serious physical stress on the worker, therefore continuous activity was not tolerable, and the work had to be interrupted for periods of rest. Industry, however, required increased performance, and that could only be realized through automation.

Their application leads to increased productivity, decreased cycle of production time, better quality, and the amount of hard and monotone work can be decreased, with their help human activity can be replaced in environments that are dangerous to health [11].

Welding is a relatively new use of robotics, the industry was created by the robots itself. In 1962, General Motors used resistance spot welder robots on the welding production line.

Robotic welding procedures have come a long way since the first spot welding robot in 1962. Now implemented across varied industries, manufacturers recognize the benefits of robotic welding to keep them competitive in an ever-expanding and highly competitive global marketplace.

From the tools of mechanization – by application features – manipulators stand out, just as the flexibly programmable, industrial robots working alongside peripheries Figure 3. shows the automatization tool kit of the welding [11].

The flowchart provides a comprehensive visual representation of the tool kit components and functions involved in welding automation, starting with, The Operation of Technological Material Flow (describes the flow of materials through the welding automation process) is divided into three, The Transport (Involves the movement of materials within the welding cell), The Treatment (Refers to any specific treatment processes applied to the materials during welding), and the Orientation (Ensures the correct positioning of welding materials). taking us to the Handling Equipment (Equipment used to manipulate materials during the welding process), and the Main Function (The primary purpose of each component in the welding automation system) is divided into Five, the Storage Equipment (Equipment used for storing materials before or after welding), the Dispensing Equipment (Equipment responsible for dispensing necessary materials for welding), the Moving Equipment (Equipment involved in moving materials within the welding cell), the Holding Equipment (Equipment used to secure materials in place during welding), and the Testing Equipment (Equipment for quality control and testing of welded materials). us to the Function Share (How different components interact and share functions in the welding process) is divided into two, the Moving Unit with Fixed Main Functions (Units with predetermined functions for specific tasks), and the Moving Unit with Variable Main Functions (Units capable of adapting functions based on requirements). taking us to Motion Training (Training processes for the movement of equipment) is divided into two, the Programmable Moving Unit (Units that can be programmed for specific movements), and the Hand Controlled Moving Unit (Units controlled manually for precise adjustments). taking us to the Program Change (Process for changing programmed functions) is divided into two, the Fixed Programmable Manipulator (Manipulators with fixed programming for repetitive tasks), and the Free Programmable Manipulator (Manipulators with flexible programming for various tasks). All of them combine present the Industrial Robot (Overview of the role of industrial robots in welding automation).

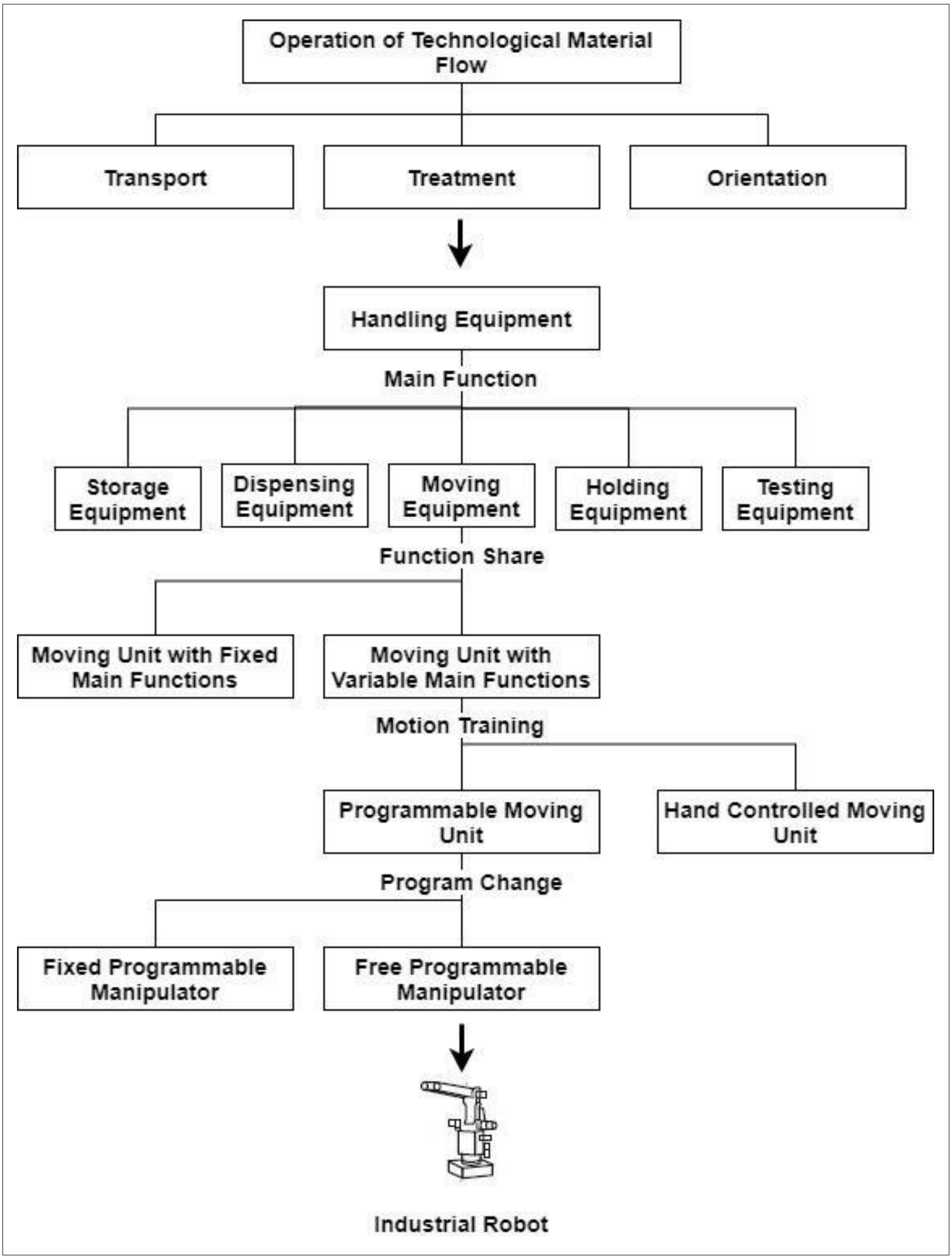


Figure 3 The tool kit for the welding automatization [11]

5.3 Some of the main benefits of robotic welding include

– Quality: Robots can make high-quality, precise welds. They are also able to repeat these welds with the same quality. The result is consistent, reliable welding.

– Productivity: Robots improve productivity on an assembly line. They are capable of complicated simultaneous welds; they work fast, without sacrificing quality; they have reliable repeatability, and they work tirelessly. Robotic welding significantly speeds production and results in a significant Return on Investment (ROI) over the long term.

– Safety: Until the mid-twentieth century, humans performed all welding processes. This exposed them to hazardous environments and toxic fumes. Robotic welding eliminates the dangers associated with welding.

Robots are helping manufacturers meet the new demands of an expanding competitive landscape by being able to perform hazardous and complicated welds with higher quality and repeatability, lower costs and higher productivity. With sophisticated new robots, robotic welding has opened up opportunities in non-traditional applications too.

Cloos International also manufactures and develops welding equipment, including power supplies and robots. for high-performance process- es, robot welding processes have been developed. Besides, various sensors help the work of the welding robots.

The welding robot is shown in Figure 4. can achieve displacement around 7 axes. The robot's workspace can be described by a hemisphere, each point can be reached by the robot.

During our welding experiments, we checked that the robot could weld in all positions. The robot presented and used by us is digitally controlled. The programming must be implemented in the programming language developed by Cloos, during which, in addition to the knowledge of coordinate geometry, welding knowledge is also required.

Welding is performed by a robot with gas metal arc welding technology. The welding current achievable is significantly higher than in the case of hand welding, incorporating a welding speed resulting in higher productivity that significantly exceeds manual welding.

Figure 4 Cloos welder robot (OE BGK laboratory 2021.)(author)

5.4 Robots in Industry 4.0

Robotics become the most important part of Industry 4.0. Nowadays they are in collaboration with human workers, but in some parts of the work chain, they can work alone controlled by a program. The human-robot interaction needs to be more defined to increase the applicability of the robots. The innovation of robots by artificial intelligence makes them suitable for all difficult work. Robots can take over the non-ergonomically workplaces in mining, welding, casting, etc.

Industry 5.0 is only a plan, but it can be seen, that future industries will be autonomous without human workers.

The collaborative robot developments supported by the various sensors can enable the possibility of collaborative welder robot availability. The welding task is metalworking where automatization facilitates and speeds up the process. It would be a great advantage for the industry if, in the place of the human welder, it could apply collaborative welder robots.

The collaborative welder robot application in place of the manual welders will be available soon, but to ensure the welding quality and also the safety of the human co-workers, standardize the collaborative welder robot environment configuration.

Figure 5 shows how each component plays a crucial role in the vision-based flexible material feeding system, ensuring accurate and seamless operations throughout the manufacturing process. we can visualize the process as follows:

- **Bulk**: This represents the source of raw materials or components that need to be fed into the system.
- **Working Plane**: The area where the materials are processed or assembled.
- **Camera**: A vision system like a camera with a laser pointer that captures images and provides visual information to guide the process.
- **Manipulator**: A robotic arm or cobot that interacts with the materials based on the information provided by the camera.
- **Assembly Station**: The final stage where components are put together or processed.

By integrating these elements, the vision-based system can efficiently feed flexible materials into the manufacturing process. This setup allows for precise targeting and handling of materials, enhancing automation and efficiency in production processes.

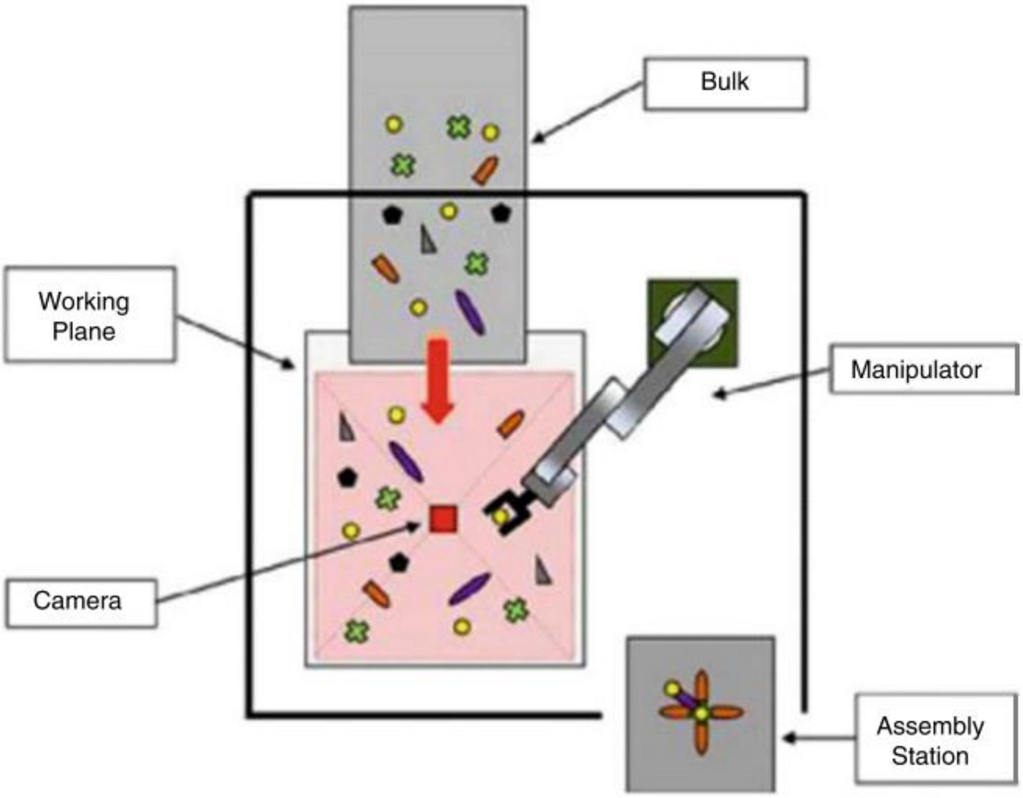


Figure 5 Vision-based flexible material feeding [12]

5.5 Collaborative robot applicability in the place of the manual welder

Collaborative robots in our age are widely used in several workplaces. The robotic rules are applied to them also. The robotic rules are defined by Asimov in his famous work [13]. Robotics increased rapidly in the last decade and we learned to live and work together with them. The first robots usually some automats were [14]. They made their program continuously without any communication with their environ observes the rules of Asimov. Nowadays used robots are different, they can communicate with their environment. The robots use sensors to pick information from their environment. Sensor technology is also increasing with robotics to support the robot designer's pretensions. Collaborative robots continuously pick environmental data [15]. The available sensor number is almost uncountable. The sensor technology base uses the picked physical properties data of the environment (f.ex. temperature, waves, currents, etc.). These are the heat sensor, the moving sensor, the light sensor, the arc sensor etc. Also, the motion of some robots and collaborative vehicles is supported by radar and GPS technology [16]. The sensor, radar, GPS, and wireless technologies are necessary to build a suitable and safe robot system [17]. The base of the robot programming is the coordinate geometry. Collaborative robots are safe for human co-workers, which means that the robot and the humans work together in the same work area [18]. The human-robot collaboration levels are shown in

Figure 6 Integration levels of the human-robot collaboration [18].

It can categorize the collaboration levels as follows:

1- Strictly Separated Robot Workspace (Contact Impossible): In this level, the robot and human work in completely separate spaces without any possibility of contact. The robot operates within a fenced area, ensuring physical separation from the human worker.

2- Part of the Workspace is Shared (Contact Only While Robot is Stopped): Here, the robot and human share some workspace, but contact is only allowed when the robot is stationary. This level involves safety measures like sensors that stop the robot if a human enters its space.

3- Workspaces are Fully Shared (Contact Possible/Desired): This level allows for full collaboration where the robot and human share the workspace and can interact physically.

Safety mechanisms like force monitoring are in place to ensure safe interaction between the human and robot.

By illustrating these three levels, we can visually represent the progression from strict separation to full shared workspace in human-robot collaboration. Each level presents different safety considerations and degrees of interaction between humans and robots, highlighting the evolution towards more integrated collaboration.

In the case of the lowest level corporation when the human and robot workplace are separated they work in the same all. Middle-level human-robot interaction when humans and robots are sharing the workplace, but not at the same time. The highest level of human-robot interaction is real collaboration when the workplace is fully shared and contact is not only possible but desired.

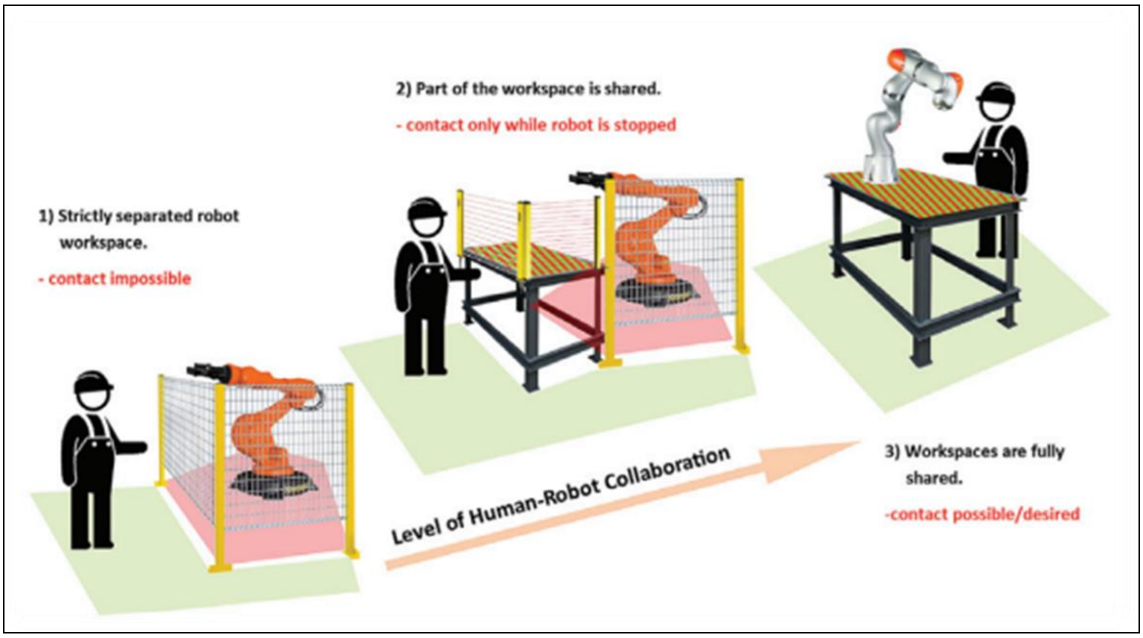


Figure 6 Integration levels of the human-robot collaboration [18].

As a part of Industry 4.0. strategy the industrial work needs to be automated with the collaboration of the robots and human workers. The collaborative robot's task is supported by several sensors. For robot control, the used sensors' kind and sensitivity are very important, they need to be suitable for the robot's task and security requirements [19]. The suitable collaborative robot system (sensors included) environment needs to be fully secured. Industrial robots are stipulated by the ISO 10218 standard [20][21][22]. The robot's control in the case of collaborative robots is realised by wireless technology. This technology assures suitable, rapid data transfer between the robot and the controller.

Unfortunately, industrial robots wireless data transfer is vulnerable [23]. The robot's programming and control as a function of the robot function are almost solved, it can find several examples and manuals in the literature [24][25].

Nowadays we can find several robots in the welding tasks. Most common are the spot welder robots in car industrial processes, and also it can find welder robots in the fusion welding area too. Commonly the robot used for fusion welding is the Gas Metal Arc Welding (GMAW) process [26][27]. The guiding and control of this welding process by a computer program is solved.

Hence the aim of the collaborative robot applicability analysis in the place of the manual welder is a complex work to establish a technical aspect system that includes the dangers and requirements of the welding and the robotics.

5.6 Summary of Industrial Robotics

Industrial robotics, particularly welding robots, have made substantial advancements in enhancing productivity, quality, and safety across diverse industries. The integration of robots in welding processes has resulted in heightened productivity, enhanced quality standards, and minimized physical strain on workers. The emergence of collaborative robots, capable of operating in conjunction with humans, is poised to broaden the scope of robotic applications across multiple industrial sectors. Industrial robotics focuses on safety requirements, automation in welding, and the use of robots in Industry 4.0. The origins of the term "robot" and the three laws of robotics form the foundation of robotics science. Safety regulations for industrial robots and the need for well-trained operators are crucial. The use of robots in welding offers benefits such as increased productivity, better quality, and improved safety. Collaborative robots are highlighted for their potential role in Industry 4.0 and beyond, emphasizing a safer and more efficient human-robot collaboration in industrial settings.

6 RISKS OF THE GMAW

Manual welding is hard physical work for the human welder. The welded joint quality depends on the welder's knowledge and experience. The manual welder is limited by his physical and environmental conditions. The welding speed and the applicable power source namely the productivity of the welder are limited by these parameters. The industry is expecting higher and higher productivity which is impossible to perform by manual welding. Also, labour safety requirements are increased to save workers' health. In this aspect truly the expectation is to replace manual welders with collaborative welder robots. These collaborative welder robots need to be integrated between manual welders and welding inspectors. To satisfy this expectation it needs to define the probable dangers for humans during the welding task of the collaborative welder robots.

During the GMAW process, it can find several dangers from the process specification and the process of metal transfer. The base of arc welding is the melted metal transfer between the electrode and the weld metal pool to establish a metallic joint. The melting of the metal is made by an electrical arc. In the high-temperature electrical arc, any metal can be melting. The melted metal temperature is much over than the melting point of the metal. The melted metal during the metal transfer process is covered by shielding gas to isolate the melted metal from environmental pollution.

Dangers of the GMAW process on the base of the ANSI Z49.1 [28]:

Heat (electrical arc heat, high-temperature product)

UV light (electrical arc)

Spattering (melted metal drops

Fume (established gas mix from the metal component and shielding gas

Robot „arm” (movement of the robot)

Based on international and national laws in the case of any welding, manufacturing needs to observe the Welding Safety Regulation requirements [29]. This regulation contains the rules for automated welding workshops. Regulated the distance between the robot standard and moving parts and the workshop walls, pillars and other devices. In the workplace, the robot can stay only the educated operator. To enter the robot risk zone is forbidden. The configuration of the robot environs needs to be suitable to observe these rules. In the robot risk zone, only the robot maintainer staff can stay during robot installation, calibration and maintenance. The collaborative human worker needs to wear protective clothes, gloves, and a helmet as in the case of manual welding.

6.1 Heat risk of GMAW

Gas Metal Arc Welding (GMAW) poses risks related to heat, affecting both equipment and welders. Overheating in GMAW guns can lead to catastrophic failure, impacting weld quality and productivity. Signs of overheating include the gun becoming uncomfortably warm, indicating potential damage or failure. Manufacturers rate GMAW guns based on temperature rise and duty cycles, crucial for preventing overheating issues [30]. Welders are particularly vulnerable to heat stress problems due to the heat generated by welding tools and the welding arc. Preventing heat-related issues while welding is critical. High temperatures can produce heat stress, resulting in symptoms such as heatstroke that necessitate emergency treatment. Factors like age, health problems, and medications can raise the risk of heat-related diseases. Recognizing indicators of heat stress and taking proper breaks is critical for avoiding significant consequences [31].

In GMAW, flaws like burn-through and porosity can occur due to excessive heat or inadequate shielding gas. Porosity, caused by trapped gas in the weld metal, weakens welds and requires rework. Burn-through, where the weld penetrates the base metal, is a common flaw at high temperatures. Proper gas flow, nozzle size, and cleanliness are essential in preventing porosity while controlling travel speed can help combat this flaw [32].

When wearing a welding helmet, the distance from the helmet to the weld is not specified. However, a welder should maintain a comfortable distance from the weld, ensuring they can view the puddle clearly without getting too close to the heat source. This distance may vary depending on the welder's experience and comfort level, but a typical distance for MIG welding is 16 to 18 inches (40 to 45 cm) [33].

Understanding the dangers associated with heat in GMAW processes is critical to ensuring safety, equipment integrity, and weld quality. Proper protections, such as monitoring for signs of overheating and adhering to recommended practices, can help effectively limit these hazards.

The ANSI Z49.1 standard refers to the heat for human health risk of arc welding [28]

ISO standard of Safety of Machinery – General principles for design – Risk assessment and risk reduction refer to the danger of the welding heat [22]

6.2 UV light danger

The GMAW robot operator can serve and/or collaborate in the work of the robot only in the dangerous light-separated area. The GMAW used electrical arc dangerous light emission (ultraviolet (UV) and infrared (IR)) depending on the welding parameters. The light spectrums are shown in Figure 7. between 750 nm to 400 nm. The visible light spectrum area for a human is limited. Also, dangerous UV and IR lights are defined for human eyes and skin [28].

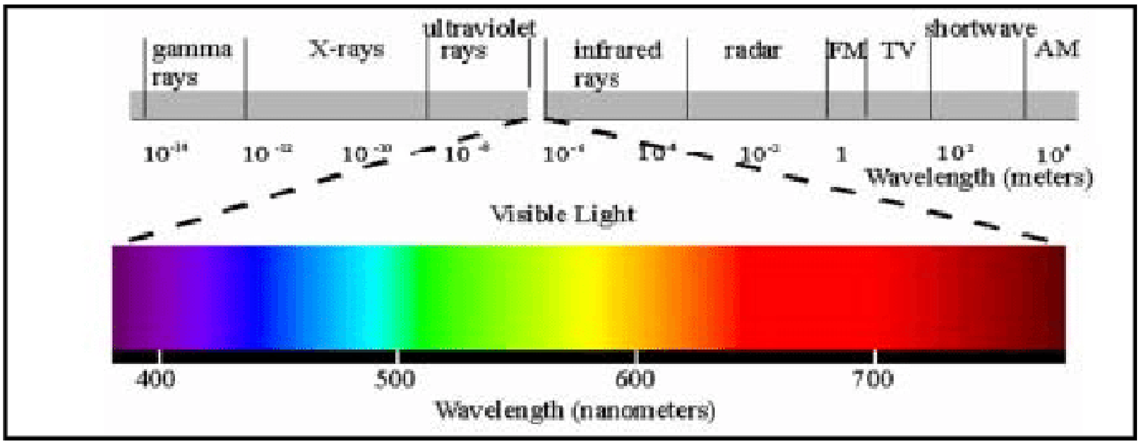


Figure 7 Visible spectrum for the human eye [34].

The operator can work with the GMAW robot in the case of suitable air exchange or air ventilation. In the case of any alarm, the operator needs to go to the assigned safe area [34].

The welding arc emission radiation in a wide range spectrum 200–1400 nm or 0,2–1,4 µm. This spectrum contains the ultraviolet (UV) areas (180-400 nm), the visible light (400-700 nm) and the infrared (700-1400 nm). The UV contains three kinds: UV-A waves (315-400 nm), UV-B waves (280- 315 nm) és UV-C waves (100-280 nm) Table 1 [35].

Table 1 The UV radiation spectrum (data from [35] *)*

Wavelength region	**Wavelength range**
UV-C	100-280 nm
UV-B	280-315 nm
UV-A	315-400 nm

Light is an electromagnetic wave, this radiation can be visible or invisible. The fundamental unit of the optical power is defined by Planck’s equation (5.1):

$$Q = \frac{h \cdot c}{\lambda} \tag{5.1}$$

Where Q is the photon energy (J), h is the Planck’s constant (6,623·10-34 Js), c is the speed of light (2,998·108 m/s) and λ is the wavelength of radiation (m) [36]. The wavelength is related to the frequency, υ, calculated by the equation (5.2):

$$\lambda = \frac{c}{v} \tag{5.2}$$

The UV radiation group's wavelength can be determined by (5.1) and (5.2) equations (Table 1) [37]. UV radiation as a function of the photon energy can cause health problems because the energy is absorbed in the human skin or eyes. The UV light as a function of UV level and the exposition time can cause conjunctivitis or vision impairment [37] [38] [39]. UV radiation has a cumulative effect on the eyes and skin [40]. The limit of the UV radiation exposition can be determined by the standard suggested method of Photobiological safety of lamps and lamp systems [41]. Also, it needs to be considered the Hungarian statute, the minimum health and safety requirements for the exposure of workers to artificial optical radiation [42].

Figure 8. shows the UV radiation effects on the eyes.

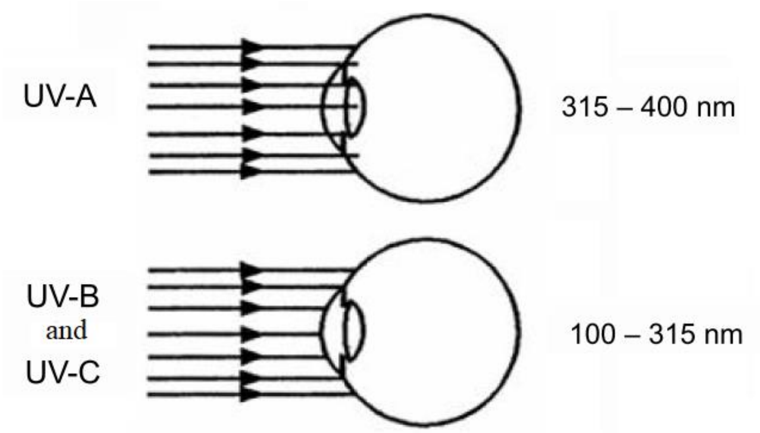


Figure 8 Radiation effect on the eye [40]

The time of the exposition (what is the reason for the health effect) depends on several aspects, including the radiation intensity, the distance between the eyes and the arc, the angle of the radiation, and the shielding of the eyes [43] [44]. During arc welding, the visible light is very strong and the eyes can not be able to adapt to it.

A daily maximum limit for UV radiation can be interpreted as the amount of time a given worker can stay in an area exposed to UV at a given intensity. This limit is given in mW/cm^2 and the daily highest value one person can handle is 3 mW/cm^2, more than that can already be harmful to the worker. One of our measurements, which was performed outdoors on an overcast winter day, where the amount of UV radiation from the sun was 0.001-0.002 mW/cm^2, may help to interpret this. It would follow that 30-60 minutes could be spent outdoors. This is because we also take into account the UV-C radiation when setting the limit value, which is filtered out to the full extent by the Ozone Layer, so the values change positively for us [45]. The radiation effect can be interpreted by considering the exposition time. In the case of UV radiation, the safety value interpreted for one day (UV radiation /day) was established.

During the welding, it needs to use a helmet to cover and save the eyes of the welder. In the welder workshop, the workstations are separated by a special curtain or wall, to assure the safety of the other people. The modern workshop wants to use robots and collaborative robot welders which can move between the workstations. The welding process is a special task in the case of automatization if it wants to use robots and human welders in the same workshop. In a big workshop, the welders are not separated by walls, they can move between each other when they move the other workstation. The concept is the same with the welder robot, it needs to work and collaborate with human welders. The welding arc established UV radiation intensity depending on the welding current and the used shielding gas, as defined by high numbers of research work results [37] [45] [46].

6.3 Danger Spattering (melted metal drops)

Weld spatter, common in Gas Metal Arc Welding (GMAW), poses various risks and challenges during welding operations. Spatter consists of droplets of molten material that can lead to issues like sticking to workpieces, causing burns, loss of material, and excessive clean-up [47]. Factors contributing to the spatter include disturbances in the molten weld pool due to incorrect Amperage and Voltage settings, improper wire feed speed, poor welding surface conditions, and improper torch angles. To reduce spatter, it is crucial to maintain proper control settings, practice on clean scrap metal to find the right settings, use suitable welding techniques like keeping the MIG torch angled correctly, and ensure a clean metal surface free from contaminants like dirt or coatings not designed for welding [47][48][49]. Additionally, selecting high-quality metals suitable for welding and adjusting welding techniques can significantly minimize spatter generation [48].

The ANSI Z49.1 standard refers to the flying sparks, and molten metal for human health risk of arc welding [28]

6.4 Fume (established gas mix from the metal component and shielding gas)

Welding fumes generated during Gas Metal Arc Welding (GMAW) can pose significant health risks to workers. These fumes consist of particles of metal, metal oxides, and flux, which can contain various hazardous substances like aluminium, beryllium, manganese, chromium, iron, cadmium, nickel, copper, lead, zinc, and others. Exposure to these fumes can lead to immediate effects like eye, nose, and throat irritation, dizziness, nausea (commonly known as Welder’s sickness), and even metal fume fever with flu-like symptoms lasting 24-48 hours. Long-term exposure to welding fumes can result in lung damage and other serious health issues [50].

The composition of welding fumes varies depending on the welding method, welding rod composition, base metals used, coatings applied, location (open area or confined space), and ventilation controls. Adequate ventilation in the workplace is critical to preventing the collection of fumes and gasses. Workers should also wear suitable respiratory protective equipment as part of the company's respiratory protection program to reduce their exposure to welding fumes [51].

Employers must conduct hazard assessments and implement control measures to ensure the health and safety of workers exposed to welding fumes. It is essential for individuals working with welding processes to be aware of the hazards associated with welding and take necessary precautions to reduce exposure levels to safe limits [52].

The ANSI Z49.1 standard refers to the fume and gases for human health risks of arc welding [28].

6.5 Robot Application Hazards

Industrial robot applications might provide risks at any point in the normal lifecycle's phases or operations.

6.5.1 Manufacturing the Robot Systems and Applications

These businesses have particular risks related to producing individual parts for use in robot systems. Many of the risks mentioned above are usually encountered during the robot applications' manufacture, installation, and testing. The following risks need to be taken into account:

- Impact, struck-by, caught-between, and projectile-strike risks. Workers initially come into contact with the robot application during assembly, installation, and testing. Errors in design, assembly, and installation will manifest throughout these phases.
- Perils related to electricity, hydraulics, or pneumatics. Termination or connection issues may also arise during assembly and installation and go undetected until the first testing.
- Depending on where and how the assembly, installation, and testing are done, there may also be other mentioned dangers.

6.5.2 Integrating Robot Applications

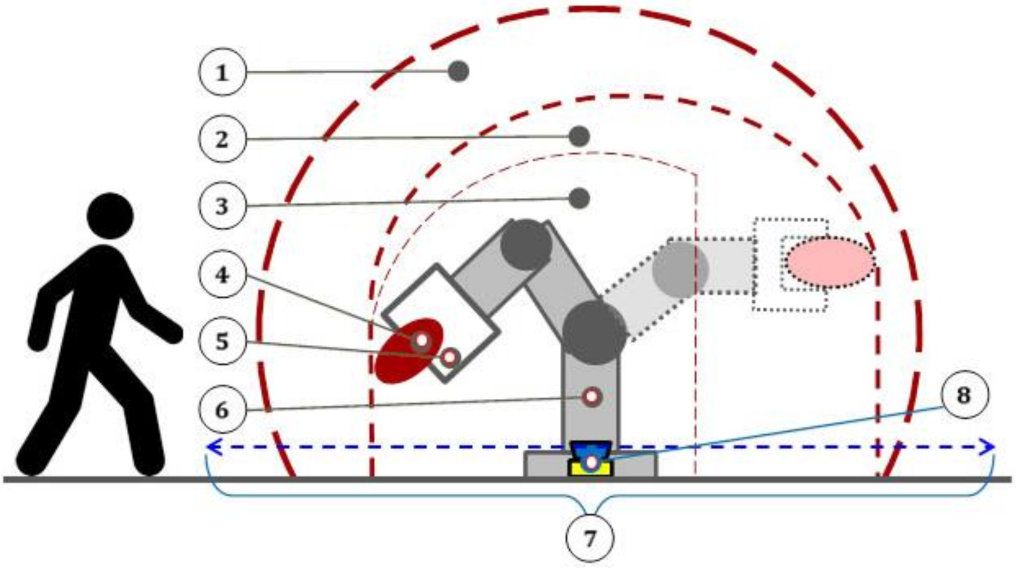
Until the robot system is integrated for usage in corporate facilities, the robot application's full capability is frequently not available. Any end-effectors, sensors, protective measures, control devices, or other fixtures required for the robot application to carry out its intended task(s) should be included in the finished robot application. Certain users (employers) and certain robot manufacturers also serve as integrators of their robots by offering robot integration for certain applications

This is frequently the initial location where people engage with robots based on their intended use. Because of this, any of the risks mentioned above might arise throughout the process of final assembly and integration, and they should all be taken into account.

6.5.3 Operating and Maintaining Robot Applications

Robot applications have operating characteristics that differ significantly from conventional machinery and equipment. Robots may move with high energy (fast and/or powerful) over a huge volume of space beyond the robot's base dimensions (see Figure 9). However, even low-energy robots that appear safe (i.e., those with payloads as little as 6-1/2 pounds or 3 kilograms) can be utilized in extremely dangerous situations.

If the object(s) being worked on and the surrounding conditions remain unchanged, the robot application's movement pattern and start time are predictable. However, it is common for application programs to be intricate, with certain moves or actions occurring infrequently enough to be surprising. Moreover, modifications to the environment or the object being worked on (such as a physical model update) may have an impact on the movements and activities [53].



Key:				
	1	maximum space	**5**	end-effector
	2	restricted space	**6**	manipulator
	3	operating space	**7**	safeguarded space
	4	workpiece	**8**	protective device or barrier (safety scanner shown)

Figure 9 Robot Application Spaces (Source: Robotics Industries Association, RIA) [53]

Collaborative robot applications, as previously said, are made especially for direct worker engagement, which may enhance the risks and hazards for workers engaged in the particular application task(s).

Some workers (for example, programmers, operators, and maintenance personnel) may be required to remain within the restricted space when actuators, valves, sensors, end-effectors, or other energy sources are powered on. The restricted space of one robot application may overlap with a portion of the restricted space of other robot applications or the work zones of other industrial machines and related equipment. As a result, a worker may be hit by one robot system or workpiece while working on another, become stuck between them or peripheral equipment, or be struck by flying items (projectiles) emitted by an end-effector or other materials.

In a robot application with two or more programs, the currently running program can call another program with different operating parameters, such as velocity, acceleration, deceleration, or position inside the robot's restricted environment. Workers performing other jobs within the robot's confined zone may not have anticipated this event.

Although robot applications have safety features that monitor and/or regulate robot capabilities such as speed, position, and acceleration, a component malfunction could result in an unexpected movement and/or change in robot velocity.

Additional risks can arise from the failure of, or faults in, the interface or programming of other processes or peripheral equipment. Even if everything is performing as designed and validated, operating changes with the process or the breakdown of conveyors, clamping mechanisms, or process sensors may produce unanticipated reactions [53]. Risk of electric shock during welding

Welding, a crucial process in construction, presents significant risks, notably the potential for electric shock. Electric shock incidents in welding typically result from contact with a live electrode or metal component, creating a path between the power source and grounded metal. The consequences of such shocks can range from mild spasms and burns to severe outcomes like muscle paralysis or fatality, influenced by variables such as voltage, current strength, and exposure duration. In welding, two primary forms of electric shock exist: primary voltage shock, characterized by higher voltages (115 V to 600 V), often occurring when handling damaged leads or exposed components within the welding equipment; and secondary voltage shock, which occurs at lower voltages (20 V to 100 V) when completing a circuit involving the electrode, welder, and grounded metal. While primary voltage shock poses a greater danger due to its higher voltage levels, secondary voltage shock is more prevalent but generally less hazardous in comparison. In welding operations, safeguarding against electric shock is paramount, necessitating welders' comprehensive comprehension of the hazards inherent in various welding techniques such as arc welding (e.g. MIG, TIG, or SMAW), which rely on electricity to generate an arc for metal fusion. Welding apparatus typically functions within voltage ranges spanning from 120 V to 575 V or higher, posing significant bodily and organ harm even at lower voltage levels. Mitigating the risk of electric shock during welding mandates adherence to safety protocols like insulating the body from the workpiece, refraining from skin or wet clothing contact with electrodes or electrode holder components, and employing dry gloves. Furthermore, maintaining dry working conditions, utilizing appropriate insulation materials like plywood or rubber mats, and exercising caution in electrically perilous settings are imperative strategies for averting electric shock incidents in welding operations. Ensuring a safe working environment during welding processes is imperative for welders and employers, necessitating a comprehensive understanding of associated hazards and the implementation of appropriate safety precautions. [54][55][56]

The ANSI Z49.1 standard refers to the electrical shock for human health risks of arc welding [28].

6.6 Summary of the GMAW risks

I introduced the risks of GMAW welding. Even if it is made manually or robotically it can define a safe distance from the source of the risk means the arc location. I introduced the risks as heat, spatters, smoke, UV, robot arc mechanical movement danger, and the electrical effects. The identified risks mean different kinds of dangers that can cause injury to the workers. To ensure a safe workplace needs to do a risk assessment of the GMAW task.

Occupational Safety and Health Administration (OSHA) recommends a safe distance of 35 feet (10 meters) from the welding area [57], from a welded sample without a welding helmet. However, this distance is intended to protect welders from the hazards associated with welding, including the risk of fire hazards, fumes, and radiation. I compared the safety distance of the different hazards and determined that between the welding risks the UV radiation affects the longest safety distance.

7 RISK ASSESSMENT OF THE ROBOT GMAW

The arc welder robot workplace needs to be safe for the workers in the same workshop. The risk assessment is based on the MSZ EN ISO 12100 standards [22]. The steps of the risk assessment are the next:

1. Determination of the limits of the technology
2. Identification of the hazards
3. Estimation of risks
4. Evaluation of risks

Figure 10 shows the flow chart of the flow of the risk assessment of the robot welding. Robot welding is a special task of robotics. The risk assessment is more difficult because it needs to take into account all risks of welding and robotics. The basic flowchart includes 7 key steps of the risk assessment [53].

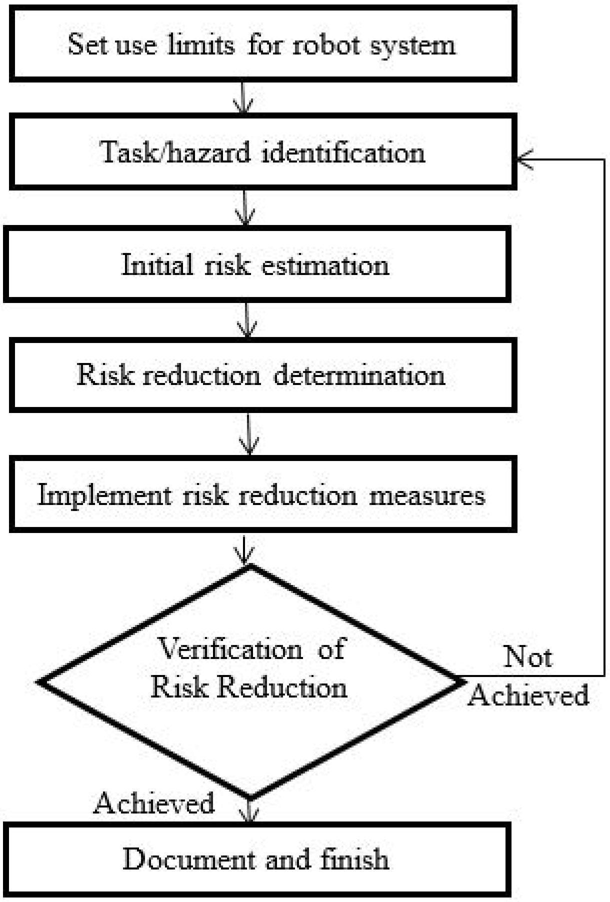


Figure 10 Flowchart of the risk assessment [53]

7.1 Limits of the technology

7.1.1 Space limit: robot arm, UV level, heat, spattering, smoke,

Aspects of space limits to be taken into account include

a) The scope of motion,
b) Spatial demands for individuals engaging with the apparatus, particularly during operational and maintenance activities,
c) Human engagement encompassing the operator-machine interface, and
d) The interface between the machine and the power supply.

7.1.2 Time limit: exposure to UV and smoke

Aspects of time limits to be taken into account include
a) Time limit as a function of the exposure level (on the base of the health limit)
b) The UV radiation accumulated, the maximum dose is limited

UV accumulation refers to the cumulative exposure to ultraviolet (UV) radiation that an individual receives over time. This accumulation occurs as a result of repeated exposure to the sun or other sources of UV radiation without adequate protection. UV radiation can penetrate the skin and cause damage at a cellular level, leading to various health risks such as sunburn, premature ageing, and an increased risk of skin cancer.

The concept of UV accumulation underscores the importance of practising sun-safe behaviours consistently throughout one's life. Even brief periods of unprotected sun exposure can contribute to the cumulative UV dose over time. Factors that influence UV accumulation include:

- Time of exposure: Longer durations of exposure increase UV accumulation.
- Intensity of UV radiation: Higher UV Index values indicate stronger radiation and faster accumulation.
- Frequency of exposure: Regular exposure without protection contributes to cumulative UV dose.
- Skin type: Individuals with lighter skin tones tend to accumulate UV radiation more quickly than those with darker skin tones.

c) Environmental Considerations: Encompasses factors like recommended temperature ranges, operational settings (indoors or outdoors), weather conditions (dry or wet), exposure to sunlight, and tolerance to dust and moisture, among other environmental variables that can impact the functioning of the machinery.

7.2 Hazard identification

The hazards and potential consequences of the robot-supported GMAW process are succinctly presented in Table 2. [22]. Following establishing the machinery's operational boundaries, a critical aspect of conducting a comprehensive risk assessment involves the methodical identification of foreseeable hazards, encompassing both persistent risks and those that may manifest unexpectedly. This process entails recognizing hazardous situations and events that could arise across all stages of the machine's life cycle, including but not limited to:

- Transportation, assembly, and installation;
- Commissioning;
- Operational use;
- Disassembly, deactivation, and disposal.

Table 2 Summarised hazards [22]

No	Type or group	Hazards	
		Origin	Potential Consequences
1	Mechanical hazards	– robot arm movement	
2	Electrical hazards	–arc; –electromagnetic phenomena; –electrostatic phenomena; –live parts; –not enough distance to live parts under high voltage; –overload; –parts which have become live under fault conditions; –short-circuit; –thermal radiation.	– burn; – chemical effects; – effects on medical implants; – electrocution; – falling, being thrown; – fire; – projection of molten particles; – shock.
3	Thermal hazards	–flame; –objects or materials with a high or low temperature; –radiation from heat sources.	– burn; – dehydration; – discomfort; – frostbite; – injuries by the radiation of heat sources; – scald.
4	Noise hazards	–welding established noise	
5	Vibration hazards	–vibration of the robot –power source vibration	
6	Radiation hazards	–low frequency electromagnetic	– burn;

		radiation; –optical ultraviolet radiation, –radio frequency electromagnetic radiation.	– damage to eyes and skin; – effects on reproductive capability; – mutation; – headache, insomnia, etc.
7	Material/ substance hazards	–fume; –flammable;	
8	Ergonomic hazards		
9	Hazards associated with the environment in which the machine is used	–electromagnetic disturbance; –lightning; –temperature;	
10	Combination of hazards		

7.3 Risk estimation

After identifying hazards, conducting a comprehensive risk assessment for each hazardous scenario is imperative by meticulously analyzing the risk components outlined in Chapter 5. An essential aspect of this process involves quantifying the emission levels to gauge the associated risks accurately. This approach facilitates the establishment of a secure working environment by:

- Assessing the risks linked to emissions
- Evaluating the efficacy of protective measures

7.4 Risk evaluation

Upon completion of risk estimation, the subsequent step involves conducting a risk evaluation to ascertain the necessity for risk mitigation measures. Should risk reduction be deemed necessary, suitable protective strategies are to be chosen and implemented. In the event of new hazards emerging, they are to be incorporated into the existing list of identified hazards, necessitating the implementation of appropriate protective measures. The attainment of risk reduction objectives and a positive risk comparison outcome, whenever feasible, instil confidence in the effective reduction of risks.

7.5 Summary of the Risk Assessment

The result of the risk assessment is that the most dangerous estimated risk is UV radiation. On the base of the risk evaluation, the hazard limitation can be realized by two methods. The human worker's work safety can be ensured with isolation from UV radiation with protective walls or clothes and helmets. the other method to ensure a safe work area is to keep the worker out of the dangerous effects.

I verified my 1st and 2nd hypotheses, (1st Hypothesis: the danger zone can be determined by the most dangerous effect (UV) of the welding in the case of GMAW and 2nd Hypothesis: an unhealthy UV level needs to be the base of the danger zone determination) based on my introduced research i can declare that:

> **Claim 1. The danger zone needs to be determined by the harmful effect which causes health risks from the longest distance of the welding in the case of GMAW, which is ultraviolation radiation (UV).**
>
> **Claim 2. For the correct safety distance determination it needs to take into account the actual UV level, which can't be more than the daily highest value one person is 3 mW/cm^2.**

8 COLLABORATIVE ROBOTS

The idea of a collaborative robot was initially announced by Colgate [58] As an intelligent Assist Device (IAD) that manipulates objects with a human operator in direct collaboration. The uniqueness of cobots is their direct contact with human operators, collective motion control, and virtual surface provision to constrain and guide the movement of workers (see Figure 11). This is supposed to result in increased efficiency, ergonomics, and safety [59][60]. High-salary production provides a high degree of automation. Mainstream automation is typically restricted to manufacturing low mix high volume. The connection between the volume of output, versatility, automation, and product variety is seen (see Figure 11).

Figure 11 A two-arm collaborative robot (Cobot) [61]

Kruger [62] defined a cobot as a mechanical tool for cooperation between humans and machines in assembly lines via direct touch.

The cobots currently being formed are linked together with multiple rotational articulations, which gain a high degree of versatility and skills to achieve each coordinate in multiple configurations [63]. These cobots guide the individual running the device and provide inspiration, versatility, and intellect. Cobots are built to communicate with other people and robots directly, sharing the workload in light of each member’s skill and power. Productivity and better ergonomics are expected to have potential advantages [64].

8.1 Cobot as an Enabler of Lean Automation in Assembly Cells

The related link between flexibility, length, variants and batch size was also seen in Heilalaya [65]. The final assembly systems are designed to be manual systems because of the need for variability in assembly tasks. Human beings are therefore the most mobile components of an industrial installation framework. Human natural intelligence helps them to respond easily to changes in demand and production requirements [66] Lean Production concepts gained traction over the past decades, promising continuous improvement through waste avoidance and emphasis on value-added activities, to increase the efficiency of production systems [67]. Approaches to combine lean production concepts in automation technology were already presented in 1990 and resulted in non-complex and less creative automation solutions. “Lean automation is a technology that uses the right amount of automation for a certain task,” Dulchlnos describes [68] as “lean automation. It emphasizes robust, reliable parts and minimizes solutions that are unnecessarily complex.” With the advent of the principles of Industry 4.0, the trend is increasingly emerging in industrial assembly processes that integrate robotics and automation into growing areas of human activity [69].

The integrated production systems of human robots are a combination of human imagination, intellect, experience, versatility and abilities, electronics and physical strength, speed, and machine precision. (see Figure 12). This method allows a mounting system to manufacture complex goods on demand at reduced costs [70].

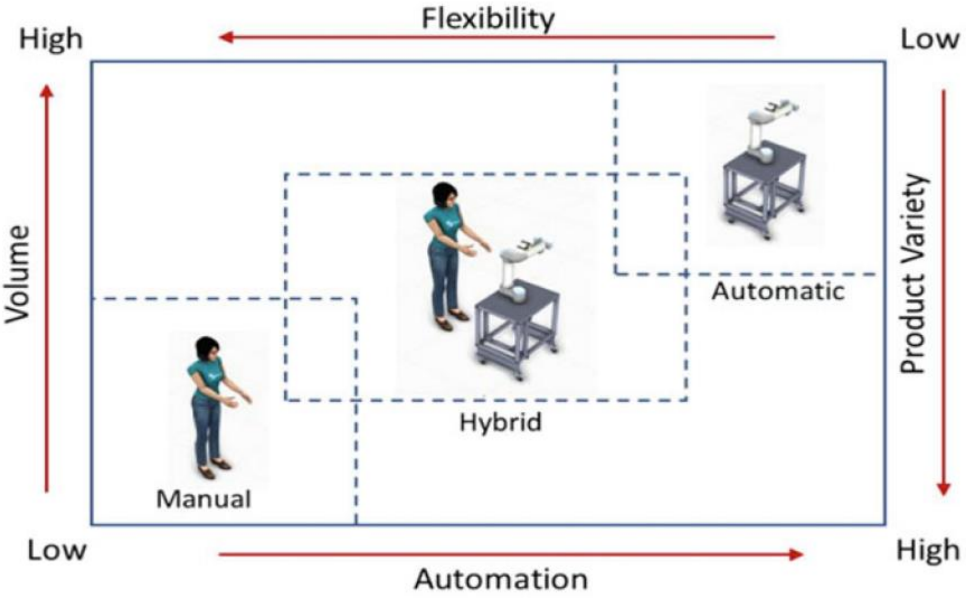


Figure 12 Flexibility and automation. (Modified from Heilala [66] *and Rosati* [12])

8.2 Selection of Cobot

Several cobots with various capabilities and strengths are available on the market. A cobot that best fits the needs of the assembly system is necessary to determine. Many researchers submitted the assessment and selection of an industrial robot as an issue of multiple criteria decision-making (MCDM).

The features or characteristics of industrial robots have been categorized as objective (numeric charges, prices, etc.) by Chatterjee [71]. and subjective (for example, versatility in programming, quality of operation, etc.). Therefore, higher values (for example, desirable values are desirable.). Carrying capacity) and unprofitable (which have lower values, including cost, repeatability, and so on) attributes [71] A variety of experiments are carried out to test and calculate the selection parameters through different scientific analyses, e.g. mathematics, statistics, simulations, etc. Finally, the analyses are standardized for comparative purposes to the same units.

Mortensen [12] submitted a literature review of 19 robot assessment scientific studies that list the parameter sets and the assessment process. In the research literature, however, the selection parameters are not determined in the robot selection process [12]. The parameters discussed so far by the researchers are also connected with a robotic manipulator’s basic functionality and are not aware that a cobot requires additional parameters for its assessment of success, such as safety, social interactions, and ease of use as a hybrid automation tool.

Andersen’s “Domain Theory” [72] indicates that many viewpoints are related to every product structure. Based on this principle, a multi-perspective approach to assessment requirements for a cobot is proposed (see Figure 13).

The following are:

- Functional view: defines the characteristics that help the cobot perform its basic functions, e.g. payload, degrees of liberty, and accuracy.
- Human-interaction view: Elements that describe the convenience and convenience of human cobot interaction e.g. programming easiness.
- Flexibility view: a cobot is expected to make the development scenarios more flexible. It must contain special features known as change enablers for this process. Wiendahl [73] Change enablers have been defined as some features that

can also be allowed at a given time to produce a design change, e.g. modular design of cobot to various conditions of reach and payload.

- Economic view: these elements describe investment-related cobot aspects.

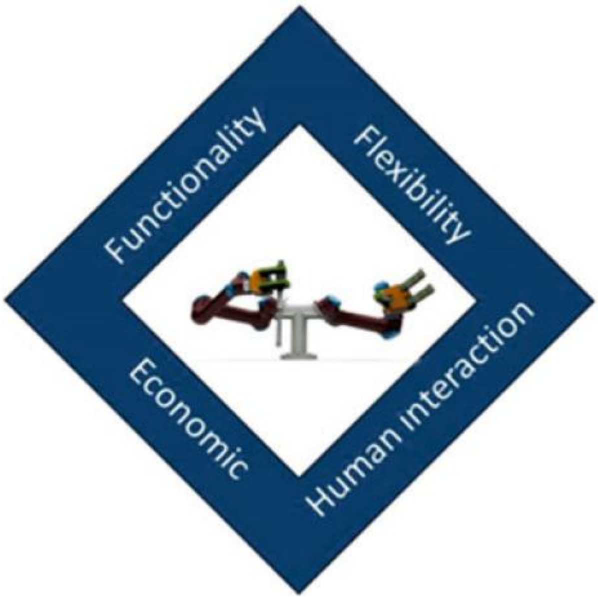


Figure 13 Different views to define cobot selection- parameters.

8.3 Safety of collaborative robots

The standard ("ISO/TS 15066 Robotics and Robotic Devices - Collaborative Robots,") contains the safety requirements for collaborative industrial robot systems [74]. The standard declares four important safety-related monitorable components of the collaborative human-robot work. The most important two components are the "speed and separation monitoring" in the human-robot collaboration. Continuously needs to ensure the safe separation distance between the robot and human during collaborative work. The second two components are the "power and force limiting" limiting the robot's transfer of pressures and forces onto the human body [75][76].

The collaborative robot by several sensors continuously monitors his work area. In the case of the detection of any foreign object, it needs to respond to the event. Figure 14. shows some robot reactions in the case of foreign object detection. The robot can react by light and sound alarm (1) when detecting the unsuitable distance between itself and the foreign object. In the case of a declined dangerous distance robot stops itself (2). The foreign object (operator) can the movement off (3). The robot can react in the case of foreign object detection by controlled collision-eliminated movement (4).

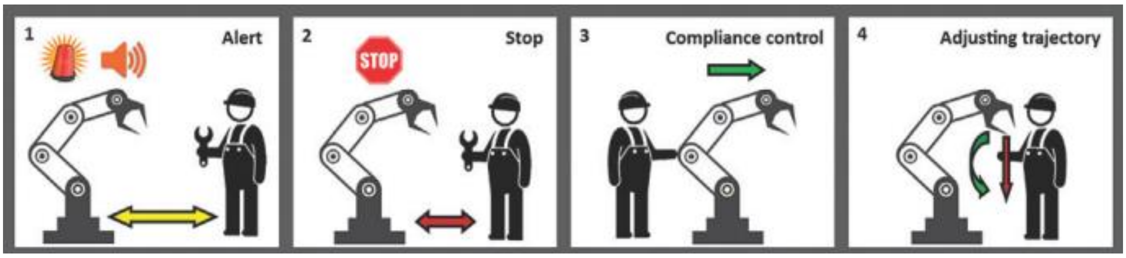


Figure 14 The reaction of the robot in the case of foreign object detection [18]

8.4 Summary of the Collaborative Robots

Collaborative robots, often known as cobots, are made to operate side by side with human operators on assembly lines, offering support and adaptability. They are designed to interact with both humans and robots, dividing up the tasks according to individual abilities and capacities. Cobots help assembly cells achieve lean automation, which improves productivity and ergonomics. A cobot's choice is influenced by several variables, such as payload, degrees of freedom, precision, ease of programming, versatility, and cost considerations. Safety is also a crucial aspect, with standards in place to ensure the safe separation distance and limiting of forces during collaborative work. These cobots provide guidance, versatility, and intellect, aiming to enhance efficiency, ergonomics, and safety in the workplace. They integrate robotics into various human activities and are equipped with sensors to detect foreign objects and react accordingly to maintain a safe working environment. Safety standards like ISO/TS 15066 emphasize monitoring speed, separation distance, power, and force to ensure safe human-robot collaboration.

9 EXPERIMENTAL STUDIES

From the several research results, it can be seen, that arc-established UV radiation depends on the welding parameters. The most important parameters are the welding current and the shielding gas. The UV radiation includes the (180-400 nm) wavelength light, which means UV-A, UV-B, and UV-C. The effective irradiance Eeff (W/cm^2) can be determined by equation (8.1) [77]:

$$E_{eff} = \sum_{180}^{400} E_\lambda \cdot S(\lambda) \cdot \Delta\lambda \tag{8.1}$$

where Eλ is the spectral irradiance at a center wavelength (W/(cm^2·nm), S(λ)relative spectral effectiveness at the center wavelength (unitless), Δλ bandwidth around the center wavelength (nm). Eeff can be measured directly with a UV radiometer [77].
The maximum exposure time per day t_{max} (s) can be determined from the effective irradiance (Eeff (mW/cm^2)) and the limited health dose (max 3 mJ/cm^2) suggested by [77] (8.2):

$$t_{max} = \frac{3\ mJ/cm^2}{E_{eff}} \tag{8.2}$$

9.1 Method of the welding arc emitted UV radiation measurement

Much research has already been done to determine the arc emitted UV radiation as a function of different shielding gases. The goal of the research is to determine a danger zone around the gas metal arc welding welder robot to ensure the safety of the human workers around in the workshop. The danger zone diameter depends on the welding parameters (shielding gas, current). The virtual border of the danger zone is flexible and always depends on the welding task. Artificial intelligence can determine the size of the danger zone as a function of the welding data and the UV daily allowable limit and let know the danger to the entering people. To determine the relationship between the welding parameters and the UV radiation level the emitted radiation during the gas metal arc welding process was measured. The test of the UV measuring was made based on the literature case studies [45] [46][78] [79] [80].

The welding flame and holder were fixed to generate an arc in the same place, and the base metal was attached to a moveable table, allowing for direct mobility during welding. The distance between the arc and the detection head was fixed to 250 mm to simulate the real distance between welders. In addition, the detector head was positioned 45° from the base metal's surface and 90° from the welding direction. The measurement time was set to 20 seconds. To exclude the time required for the arc to stabilize after the start of welding and the time required for the movable table to accelerate to the preset speed, measurements did not begin until 5 seconds after the start of welding. The measurement was repeated five times under each condition, and the values were averaged. In this study, no local exhaust ventilation system was used during the measurement of UVR because local exhaust ventilation is usually not used in welding workplaces since it might disturb the airflow around the arc, causing welding defects [45]. The applied setup of the measurement is shown in Fig. 14.

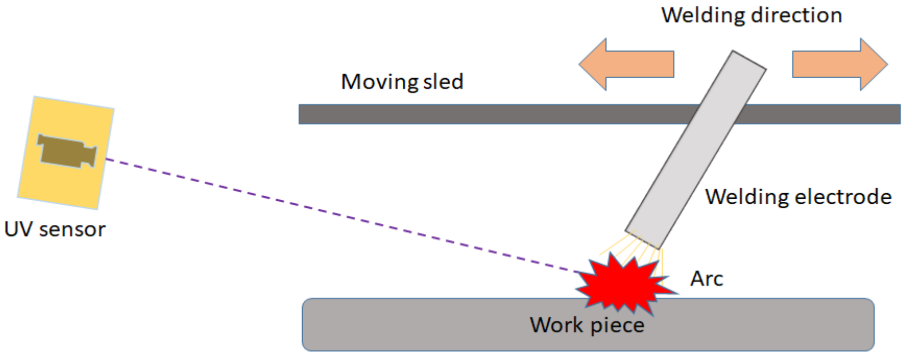


Figure 15 Schematic image of the used UV level measurement setup [experimental study] [81].

9.2 UV measuring test

It analysed the literature data and concluded that in the case of the metal arc welding process the UV radiation as a function of the distance of the UV source decreased. The measured data is collected in Figure 16. and Table 3. [37].

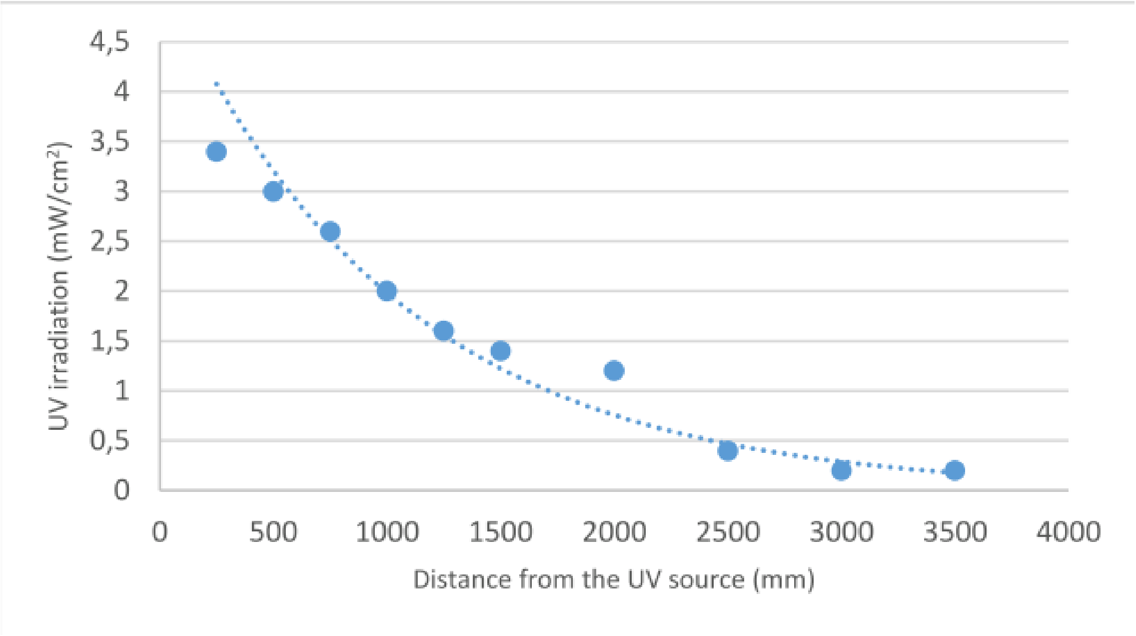


Figure 16 The effective irradiance as a function of the distance from the UV source [37]

The used literature data can apply only to the UV level tendency because the E_{eff} depends on the shielding gas and the welding current too. The data correspond with other results [45] [46] when the used shielding gas is 100% CO_2 and the welding current is a maximum of 250 A.

Table 3 The UV radiation as a function of the distance [34]

Distance from the UVsource (mm)	**E_{eff} (mW/cm^2)**	**Maximal expositiontime t_{max}**
250	3,4	0,88
500	3	1
750	2,6	1,15
1000	2	1,5
1250	1,6	1,87
1500	1,4	2,14
2000	1,2	2,5
2500	0,4	7,5
3000	0,2	15
3500	0,2	15

In a previous publication, the authors determined safety zones around a collaborative welder robot, but the zone sizes were only theoretically determined, it can be seen in

Figure 8 [82]. Based on the UV radiation level (Table 3), it can calculate the zones' sizes. The exposition time is the base of the safety zone determination because this is the maximal standing time for human people without health problems.
In this case, the zone diameter calculation needs to count the robot arm size and the UV radiation level. To determine safety zones it needs to determine the minimal escaping time of the human from the zone. The human people's horizontal speed in the case of an escape is 0,62m/s. During the zone determination, it needs to be declared. Human people can not enter the danger zone, entering the danger zone needs to stop all work affected by danger, like UV radiation and movement. The alarm zone when the infiltrator human can stay and rescue a temporary time is a maximum of 15 s, this is 3000 mm from the UV source about the Table 1. data. The alarm zone's minimal diameter from the available data is a minimum of 6000 mm. The extended zone is 8000 mm (determined from the escape human horizontal speed and the minimal alarm zone diameter). The danger zone depends on the robot arm size and required movement safety size. About the UV irradiation level, the diameter of the danger zone’s minimal size is 3000 mm where the exposition time is more than 2s.

The gas metal arc welding establishes UV radiation. UV radiation can cause health problems for human people. The welders need to protect themselves with helmets, gloves and other clothes. The safety zones around the robot welder can be determined as a function of the established UV radiation level. As followed by the required welding health standards the exposition time is determinable as a function of the effective irradiation level. The introduced research is only a nomination to determine the safety zones in a workshop where the human and collaborative robots work together without separation. The introduced determination process applies to the used welding parameters. The authors want to continue the research to determine the UV radiation dependence from the shielding gas and the welding current to create an equation for all arc welding process safety zones determination.

9.3 **Test of shielding gas effect** [81]

For the measuring three different types of shielding gas C1 (CO_2), M21 (82% Ar-18% CO_2) and M20 (10% CO_2 - 30% He - 60% Ar) were used. The main goal of the test was to make clear how the ultraviolet radiation changes depending on the distance to the source (arc). The UV level was measured at five different distances from the UV source (0,5 m; 1 m; 1,5 m; 2 m; 2,5 m). The experiments were carried out using a fixed UV radiation sensor. During the measuring a 0.5m length joint was welded. The measured ultraviolet radiation values are noted below as a function of the sensor distance from the welding arc. The experiments were performed using three different shielding gases and using different currents. The experimental parameters are shown in Table 4

Table 4 The experimental parameters (author) [81]

Variable parameters			
Current	~ 240 A	~ 202 A	~ 167 A
Feed	13 m/min	10 m/min	7 m/min
Constant parameters			
Welder wire	**SG2**	Wire extension (k)	22 mm
Workpiece material	**S235JR**	Wire thickness	1 mm

Figure 17- Figure 18- Figure 19. diagrams showing the results of the experiments. In the case of all three different shielding gases, the UV radiation decreases as a function of the distance from the welding arc. The measured data and the UV daily allowable value can be the base of the virtual risk zone conception.

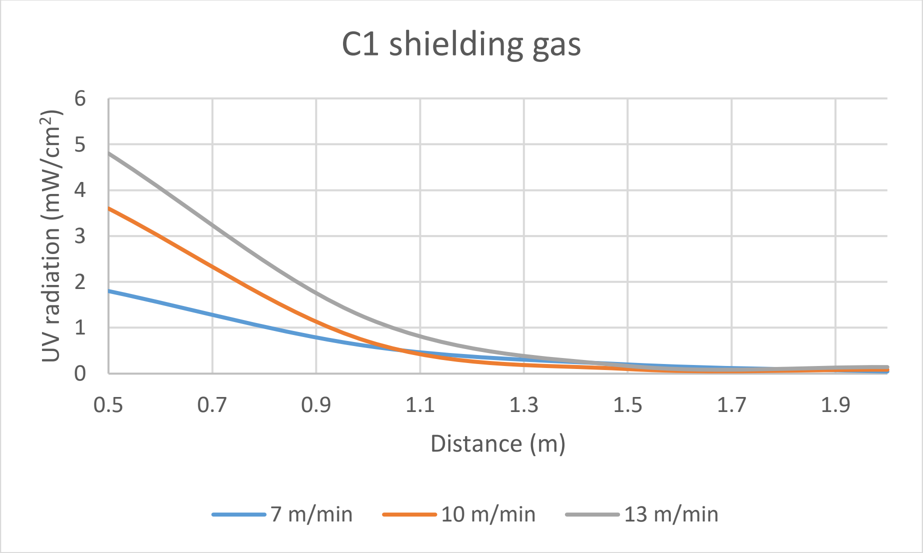


Figure 17 UV radiation level as a function of the welder arc used the C1 shielding gas (author) [81]

The most commonly applied gases in industrial applications were used in the experiments (C1, M20, M21).

Figure 17. shows the CO_2 shielding gas effect during the welding. Also, it concludes that the UV radiation level depends on the welding current, a higher current affects higher radiation. The measured maximal UV radiation level was 4.8 mW/cm2 in the case of 0.5 m distance from the welding arc.

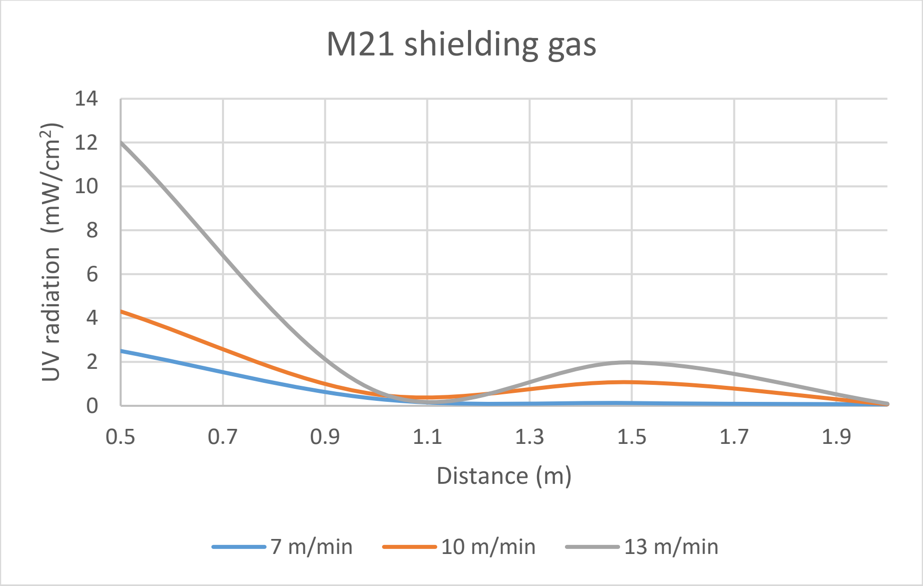


Figure 18 UV radiation level as a function of the welder arc used the M21 shielding gas (author) [81]

Figure 18. shows the Ar and CO_2 mixed gas effect during the welding. It can be concluded that the Ar gas UV shielding ability is lower than the CO_2 gas. Also, it can see the current effect. The higher welding current causes higher UV radiation. The measured maximal radiation in the case of the used M21 shielding gas was 12.2 mW/cm^2 in the case of 0.5 m distance from the welding arc.

Figure 19. shows the Ar, He, and CO_2 mixed shielding gas effect during the welding. The current tendency is similar to the case of the C1 and the M12 shielding gas results. The M20 shielding gas shows a higher UV shielding effect than the M21 gas but is lower than the C1 gas.

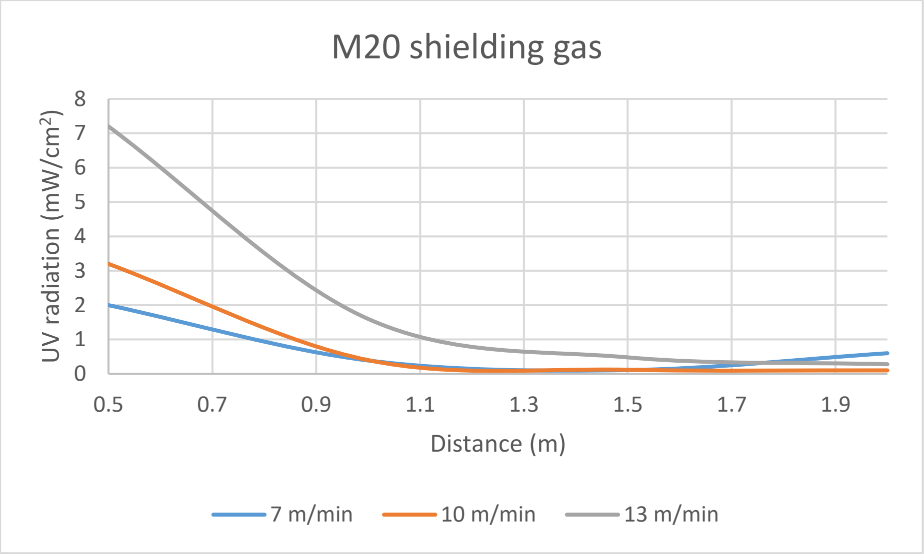


Figure 19 UV radiation level as a function of the welder arc used the M20 shielding gas (author) [81]

9.4 Summary of the Experimental Studies

UV radiation can be determined by measurement as a function of current and shielding gas. We can conclude that the increasing current elevates the UV radiation in the case of all tested shielding gases. It can be concluded that the Ar and CO_2 mix gas UV shielding ability is lower than the 100% CO_2 shielding gas UV shielding ability.

We can conclude that 0.5 m far from the UV source (welding arc) the measured UV radiation is highest in the case of M21 between the tested shielding gases.

Based on the measurement results and the daily allowable radiation limit a virtual danger zone can be defined. The size of the danger zone depends on the composition of the shielding gas and the welding current. By using artificial intelligence and measuring continuous UV values with a sensor, a virtual dynamically changing danger zone can be defined to ensure the protection of the person entering.

Based on my experimental results, I verified my 3rd hypothesis, that it needs to determine the danger zone diameter from the welding parameters (power, welding speed and shielding gas) in the case of GMAW and I declare that:

> **Claim 3. It needs to determine the danger zone diameter from the welding parameters (power, welding speed and shielding gas) in the case of GMAW because the UV radiation level depends on the welding parameters.**

10 SAFE COLLABORATIVE GMAW ROBOT WORK AREA

On the base of the collaborative robot safety standard and the risks of the GMAW, it can recommend a safety rule system for collaborative welder robots workplace configuration.

The automatization for welding aims to apply the robots in place of manual welders. The robots must work as manual welders. The human has six senses of monitoring the environment around him. Humans are continuously deciding about their operation. Human will not stop their welding task when any foreign object approaches their workplace.

A manual welder can be more dangerous than a robot for foreign humans because he wants to do a quality welded joint without any break. After all, the welding task requires determined length welding to manufacture a suitable quality welded joint. It can’t use the speed, power and force limitation in the welding manufacturing, because any limits during the welding process cause substandard product. This is the reason why it needs to support the undisturbed welding time. Breaking in the welding task causes unsuitable joints. It needs to configure the welder robot workplace on the base of the (ISO) regulations and support the welding quality availability.

The Asimov rules are suitable in robotics, robots can't cause any damage to humans not even the welded joint will be unsuitable.

10.1 Danger zones determination

On the base of the robotics safety standards and the welding process technicalities, it needs to prevent foreign humans from entering the welding zone. To support the collaborative welder robot in its undisturbed working, it can define risk zones. Figure 20. The collaborative robot must monitor not only its workplace but must monitoring also the extended zone of its workplace.

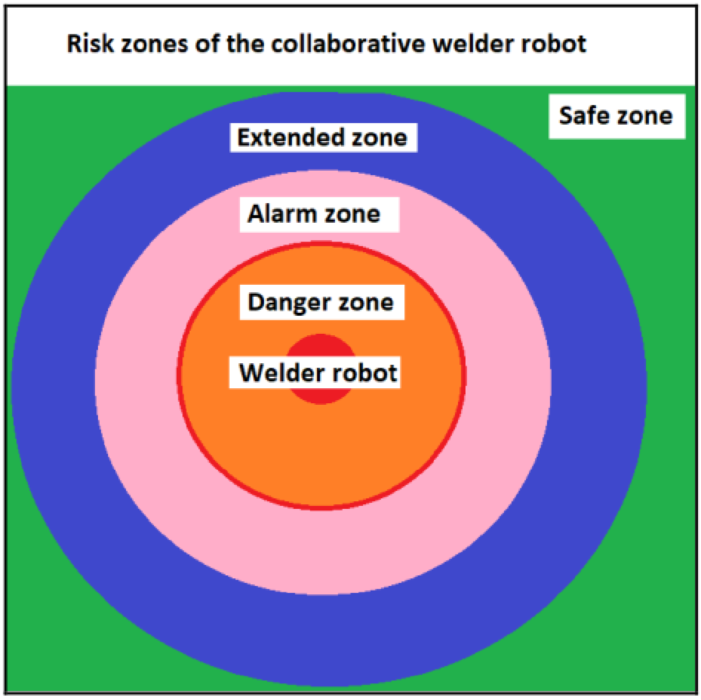


Figure 20 The collaborative welder robot risk zones (author) [82]

The extended zone means a prevention zone. If the robot detects any foreign object in the extended zone, it can modify the foreign object's movement with sound and lighting calls. Also, the robot can make a difference between a foreign human or a foreign device entering. In the case of a foreign device, the robot doesn’t need to stop its work, because the heat, UV radiation, fume and spatterings are usually not dangerous for technical devices or the protection is solved.

To realize the monitoring of the robot's environs, the robot needs to use several sensors for a continuous collection of environmental data. The robot operation will be spent on the collected and processed data. In the case of any foreign object located in its workplace area will block the operation.

In the case of a human infiltrator, the robot needs to warn the human to leave the extended work zone. The robot must control the human moving in the extended zone and continuously warn in the case of the approaching. Therefore the robot by sensor data needs to differentiate humans and devices in its working area.

In the case of a continuous human approaching, on the base of the measured average walking speed, the robot can calculate the arrival time to the dangerous working zone. Even if the robot continuously warns the human about his unsuitable, dangerous movement, the robot can continue its welding work to the arrival time of the danger zone.

The moment that the human enters the danger zone, the robot needs to stop welding to protect human safety. During this process, the robot has a chance to wake the human to modify the moving up to the entering for the danger zone while the robot may finish the welding task.

On the base of the visible light spectrum and their danger level, it can calculate a safe distance from the emission source. The safelight distance is the distance between the human and the light emission source (welding arc) where the light intensity is enough low and can't cause any damage to human eyes and skin. The most dangerous radiation is UV and IR. It calculated the zone diameters from the UV radiation because, in the case of GMAW, it can’t find IR radiation. Calculations should take into account the recommendations of ISO 60825-1.

The Nominal Ocular Hazard Distance (NOHD) is used to determine the safe distance from hazardous radiation. The Nominal Ocular Hazard Distance (NOHD), sometimes referred to as the Nominal Hazard Distance, is the distance along the axis of the emitted beam at which the irradiance is equal to the MPE. The NOHD is dependent on beam characteristics such as power, diameter, and divergence. The NOHD is usually much greater than the largest dimension of your laboratory space.

For harmful radiation, not only the distance from the radiation but also the exposure time, defined by Maximum Permissible Exposure (MPE) should be taken into account.

One of the most useful values in laser safety calculations is the Maximum Permissible Exposure (MPE). This is the irradiance or radiant exposure that may be incident upon the eye (or the skin) without causing an adverse biological effect. The MPE varies by wavelength and duration of exposure and is documented in tables published in ANSI z136.1 standard. We can think of this as your laser safety speed limit.

I have defined the following zones based on the standard recommendations:

Danger zone: the diameter of the danger zone D_D (m) calculated from the robot's maximal arm reach A_L (m), the safe light distance L_{UV} (m) and the safety coefficient L_{S1} (m).

$$D_D=2\cdot(A_L+L_{UV}+L_S)\ (m) \tag{9.1}$$

Alarm zone: the diameter of the alarm zone D_A (m) calculated from the diameter of the danger zone D_D (m) and the average human walking speed v_H (m/s), the reaction time t_R (s) and safety coefficient L_{S2} (m).

$$D_A=D_D+2\cdot(v_H\cdot t_R+L_{S2})\ \text{(m)} \tag{9.2}$$

Extended zone: the diameter of the extended zone D_E (m) calculated from the diameter of alarm zone diameter D_A (m) and a safety coefficient L_{S3} (m).

$$D_E=D_A+2\cdot L_{S3}\ \text{(m)} \tag{9.3}$$

The determined zone diameters depend on the robot's maximal arm reach A_L (m) because the safe UV light distance L_{UV} (m) is constant.

10.2 Summary of the Safe Collaborative GMAW Robot Work Area

The collaborative robot developments supported by the various sensors can enable the possibility of the collaborative welder robot availability. The welding task is metalworking where automatization facilitates and speeds up the process. It would be a great advantage for the industry if, in the place of the human welder, it could apply collaborative welder robots. It can conclude a rule, that it needs to keep out the foreign human in the welding work. To realize this rule the collaborative robot needs to recognize the foreign human and use tools to keep him from entering the dangerous area.

I determined the necessity of the risk zones in the case of the collaborative welder robots. It can be concluded that the calculation of the risk zone diameters depends on the maximal robot arm reach and the human walking speed and reaction time.

The next part of the research work focuses on determining the safe (UV and IR) light distance and the safety coefficient in the different zones. To realize this plan it needs to do several tests in industrial workplaces and analyse the human-robot interactions.

The collaborative welder robot application in place of the manual welders will be available soon, but to ensure the welding quality and also the safety of the human co-workers, standardize the collaborative welder robot environment configuration.

Based on my experimental results, I verified my 4th and 5th hypotheses (4th Hypothesis: to ensure the safety of the welding robot workplace it needs to define different danger level zones around the welding and 5th Hypothesis: collaborative robots can be used without physical barriers only when the danger zone is defined

and the crossing people must hold out by sensors and alarm systems) in this case I declare that:

> **Claim 4. To ensure the people's safety around the welding robot workplace, and ensure the welding work quality it needs to define three different danger level zones around the welding (extended zone, alarm zone and danger zone)** [82]**.**
>
> **Claim5. Collaborative robots can be used without physical barriers only when the danger zone is defined and the crossing people are held out by sensors-supported alarm systems** [82]**.**

10. SUMMARIZERIZED CONCLUSIONS

New scientific results

Claim 1: The danger zone needs to be determined by the harmful effect which causes health risks from the longest distance of the welding in the case of GMAW, which is ultraviolation radiation (UV) [82]**.**

The UV light as a function of UV level and the exposition time can cause conjunctivitis or vision impairment [37] [38] [39]. The time of the exposition (what is the reason for the health effect) depends on several aspects, including the radiation intensity, the distance between the eyes and the arc, the angle of the radiation, and the shielding of the eyes [43] [44]. During arc welding, the visible light is very strong and the eyes can not be able to adapt to it.

Claim 2.: For the correct safety distance determination it needs to take into account the actual UV level, which can't be more than the daily highest value one person is 3 mW/cm^2 [82]**.**

A daily maximum limit for UV radiation can be interpreted as the amount of time a given worker can stay in an area exposed to UV at a given intensity. This limit is given in mW/cm^2 and the daily highest value one person can handle is 3 mW/cm^2, more than that can already be harmful to the worker. One of our measurements, which was performed outdoors on an overcast winter day, where the amount of UV radiation from the sun was 0.001-0.002 mW/cm^2, may help to interpret this. It would follow that 30-60 minutes could be spent outdoors. This is because we also take into account the UV-C radiation when setting the limit value, which is filtered out to the full extent by the Ozone Layer, so the values change positively for us [45]. The radiation effect can be interpreted by considering the exposition time. In the case of UV radiation, the safety value interpreted for one day (UV radiation /day) was established.

Claim 3.: It needs to determine the danger zone diameter from the welding parameters (power, welding speed and shielding gas) in the case of GMAW because the UV radiation level depends on the welding parameters [82]**.**

UV radiation can be determined by measurement as a function of current and shielding gas. We can conclude that the increasing current elevates the UV radiation in the case of all tested shielding gases. It can be concluded that the Ar and CO_2 mix gas UV shielding ability is lower than the 100% CO_2 shielding gas UV shielding ability.

We can conclude that 0.5 m far from the UV source (welding arc) the measured UV radiation is highest in the case of M21 between the tested shielding gases.

Based on the measurement results and the daily allowable radiation limit a virtual danger zone can be defined. The size of the danger zone depends on the composition of the shielding gas and the welding current. By using artificial intelligence and measuring continuous UV values with a sensor, a virtual dynamically changing danger zone can be defined to ensure the protection of the person entering.

> **Claim 4.: To ensure the people's safety around the welding robot workplace, and ensure the welding work quality it needs to define three different danger level zones around the welding (extended zone, alarm zone and danger zone)** [82]**.**

On the base of the visible light spectrum and their danger level, it can calculate a safe distance from the emission source. The safelight distance is the distance between the human and the light emission source (welding arc) where the light intensity is enough low and can't cause any damage to human eyes and skin. The most dangerous lights are UV and IR. It calculated the zone diameters from the UV radiation because, in the case of GMAW, it can’t find IR radiation.

Danger zone: the diameter of the danger zone D_D (m) calculated from the robot's maximal arm reach A_L (m), the safe light distance L_{UV} (m) and the safety coefficient L_{S1} (m).

$$D_D=2\cdot(A_L+L_{UV}+L_S)\ \text{(m)} \qquad (9.1)$$

Alarm zone: the diameter of the alarm zone D_A (m) calculated from the diameter of the danger zone D_D (m) and the average human walking speed v_H (m/s), the reaction time t_R (s) and safety coefficient L_{S2} (m).

$$D_A=D_D+2\cdot(v_H\cdot t_R+L_{S2})\ \text{(m)} \qquad (9.2)$$

Extended zone: the diameter of the extended zone D_E (m) calculated from the diameter of alarm zone diameter D_A (m) and a safety coefficient L_{S3} (m).

$$D_E=D_A+2\cdot L_{S3}\ \text{(m)} \qquad (9.3)$$

The determined zone diameters depend on the robot's maximal arm reach A_L (m) because the safe UV light distance L_{UV} (m) is constant.

Claim 5.: Collaborative robots can be used without physical barriers only when the danger zone is defined and the crossing people are held out by sensors-supported alarm systems [82]**.**

The collaborative robot developments supported by the various sensors can enable the possibility of the collaborative welder robot availability. The welding task is metalworking where automatization facilitates and speeds up the process. It would be a great advantage for the industry if, in the place of the human welder, it could apply collaborative welder robots. It can conclude a rule, that it needs to keep out the foreign human in the welding work. To realize this rule the collaborative robot needs to recognize the foreign human and use tools to keep him from entering the dangerous area.

RECOMMENDATIONS

AI application to detect humans around the welding robot, apply more sensors and heat cam to detect correctly the people entering at the extended zone.

Measuring the people's speed around the welder robot and supported by AI, which can calculate the expected moment of entering as a function of the people's direction and speed at the extended, alarm and danger zone, to ensure the welding process is undisturbed and the quality of the welded joint.

Advanced Sensor Integration: Implement more advanced sensor technologies, such as 3D cameras, LiDAR sensors, and infrared sensors, to provide a comprehensive understanding of the environment around the welding robot. These sensors can detect and differentiate between humans and machines based on their unique characteristics and movements.

Machine Learning Algorithms for Human Recognition: Create advanced machine learning algorithms capable of analyzing sensor data in real-time to reliably detect and classify humans and machines in the robot's surroundings. By training AI models on multiple datasets, the robot can enhance its capacity to distinguish between distinct items with greater precision.

Behavioural Analysis with AI: Utilize AI algorithms to analyze the behaviour patterns of humans and machines in the welding environment. By understanding typical movements and interactions, the robot can predict and differentiate between human and machine actions, enhancing safety and efficiency in collaborative workspaces.

Real-time Monitoring and Alert Systems: Integrate AI-powered monitoring systems that continuously track the movements of humans and machines around the welding robot. In case of any potential risks or unauthorized entry into restricted zones, the system can trigger alerts and safety protocols to prevent accidents and ensure a secure working environment.

Adaptive Response Mechanisms: Develop AI-driven response mechanisms that allow the welding robot to adapt its behaviour based on the presence of humans or machines nearby. This adaptive capability can help the robot adjust its speed, trajectory, or welding parameters to ensure safe and efficient operation in dynamic environments.

Collaborative welder robots can improve their ability to distinguish between humans and machines by adopting these plans that make use of modern sensor technologies and AI capabilities, resulting in increased safety, productivity, and welding quality.

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LIST OF ABBREVIATIONS

BC ~ before Christ

R.U.R. ~ Rossum’s Universal Robots

RIA ~ Robotics Industries Association

ROI ~ Return On Investment

OE BGK ~ Óbudai Egyetem Gépész és Biztonságtechnikai Mérnöki Kar

GPS ~ Global Positioning System

ISO ~ International Organization for Standardization

GMAW ~ Gas Metal Arc Welding

UV ~ ultraviolet

UV-A ~ Ultraviolet A

UV-B ~ Ultraviolet B

UV-C ~ Ultraviolet C

UVR ~ Ultraviolet Radiation

IR ~ infrared

WIFI ~ wireless networking technology

SMAW ~ shielded metal arc welding

TIG ~ Tungsten Inert Gas welding

MIG ~Metal Inert Gas weldin

NOHD ~ Nominal Ocular Hazard Distance

MPE ~ Maximum Permissible Exposure

ANSI ~ American National Standards Institute

OSHA ~ Occupational Safety and Health Administration

MSZ ~ Magyar Szabvány MSZ EN ISO 12100 standards

EN ~ European Standard

IAD ~ Intelligent Assist Device

MCDM ~ Multiple Criteria Decision-Making

TS ~ Technical Specifications ISO/TS

AI ~ Artificial Intelligence

CO_2 ~ Carbon Dioxide

Ar ~ Argon

He ~Helium

S235JR ~ non-alloy structural steels with 235 MPa yield strength

SG2 ~ Welding Wire is a copper-coated steel wire for welding mild to medium tensile steel

C1 ~ CO_2 shielding gas

M20 ~ Shielding gas, a mixture of pure argon (Ar), Helium (He), and carbon dioxide (CO_2)

M21 ~ Shielding gas, a mixture of pure argon (Ar) and carbon dioxide (CO_2)

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