ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

DOKTORAL (PHD) THESIS BOOKLET

ABDALLAH KAFI

Safe Welder Robot Application in the Defence Industry

Supervisor :Prof. Dr habil. Tünde Anna Kovács

DOCTORAL SCHOOL ON SAFETY AND SECURITY SCIENCES

Budapest,10th February,2025.

Contents

Summary

My PhD thesis presents a comprehensive examination of the integration of robotic welding technologies within the defense sector, focusing on enhancing safety and operational efficiency. The research is motivated by the critical importance of high-quality welding in military applications, where the reliability and integrity of components are essential for ensuring the safety and performance of military equipment, including armored vehicles, naval vessels, and aircraft. The thesis begins with an introduction to the significance of welding in the defense industry, highlighting various welding processes such as Gas Metal Arc Welding (GMAW), Gas Tungsten Arc Welding (GTAW), and others that are crucial for constructing robust military assets. This emphasizes the growing demand for precision and quality in welding due to the evolving requirements of modern warfare and defense systems.

I employed a mixed-methods approach, utilizing both qualitative and quantitative research methodologies to investigate the risks associated with GMAW. The study identifies several hazards inherent in the welding process, including exposure to ultraviolet (UV) radiation, heat risks, spattering of molten metal, and fume generation. By conducting a thorough risk assessment, I evaluate these dangers and propose effective safety measures tailored for collaborative robotic welding environments.

A significant contribution of this research is the development of a novel "virtual curtain" concept designed to enhance safety for human welders working alongside robots. This innovative approach aims to eliminate physical barriers that can hinder productivity while maintaining a safe workspace. My findings underscore the importance of creating danger zones within collaborative welding environments to minimize risks effectively.

The thesis also explores the role of collaborative robots (cobots) in facilitating lean automation within industrial settings. I discussed how these advanced robotic systems can work alongside human operators, improving efficiency while ensuring safety through smart design and risk management strategies. The experimental studies conducted as part of this research validate the effectiveness of proposed safety measures and demonstrate their applicability in real-world scenarios.

In conclusion, the work provides valuable insights into the intersection of robotics and safety in the defense industry. By addressing critical safety concerns associated with robotic welding applications, this thesis contributes to advancing industrial practices that prioritize both worker health and operational efficiency.

Summary in Hungarian Language – Magyar nyelvű összefoglaló

Doktori disszertációm a robothegesztési technológiák védelmi ágazaton belüli integrációjának átfogó vizsgálatát mutatja be, a biztonság és a működési hatékonyság növelésére összpontosítva. A kutatást a hegesztéssel létrehozott kötések kiváló minőségű kritikus fontossága motiválja a katonai alkalmazásokban, ahol az alkatrészek megbízhatósága és integritása alapvető fontosságú, kiemelten a katonai felszerelések, köztük a páncélozott járművek, haditengerészeti hajók és repülőgépek biztonságának és teljesítményének biztosításához.

A disszertáció a hegesztés jelentőségének bemutatásával kezdődik a védelmi iparban, kiemelve a különböző hegesztési eljárásokat, mint például a huzalelektródás védőgázos ívhegesztés (GMAW), és a volfrám elektródás védőgázos ívhegesztés (GTAW), amelyek létfontosságúak a robusztus katonai eszközök építéséhez. Ez hangsúlyozza a hegesztés pontossága és minősége iránti növekvő igényt a modern hadviselés és védelmi rendszerek fejlődő követelményei miatt. Vegyes módszertani megközelítést alkalmaztam, mind a kvalitatív, mind a kvantitatív kutatási módszereket felhasználva a GMAW-hoz kapcsolódó kockázatok vizsgálatára. A tanulmány számos, a hegesztési folyamathoz kapcsolódó veszélyt azonosított, köztük az ultraviola (UV) sugárzásnak való kitettséget, a hőkockázatot, az olvadt fém kifröccsenéséből adódó veszélyt, valamint a füstképződést. Alapos kockázatértékelés elvégzésével értékelem ezeket a veszélyeket, és a collaboratív robothegesztési környezetekre szabott hatékony biztonsági intézkedéseket javaslok.

A kutatás jelentős eredménye egy új „virtuális függöny” koncepció kifejlesztése, amelynek célja a robotok mellett dolgozó emberi hegesztők biztonságának növelése. Ennek az innovatív megközelítésnek a célja a termelékenységet akadályozó fizikai akadályok kiküszöbölése a biztonságos munkaterület fenntartása mellett. Eredményeim kiemelik a veszélyzónák kialakításának fontosságát a collaboratív robotokat alkalmazó, cobotos hegesztési környezeteken belül a kockázatok hatékony minimalizálása érdekében.

A disszertáció az együttműködő robotok (cobotok) szerepét is vizsgálja az ipari környezetben történő lean automatizálás elősegítésében. Bemutattam, hogy ezek a fejlett robotrendszerek hogyan tudnak az emberi kezelők mellett dolgozni, javítva a hatékonyságot, miközben intelligens tervezési és kockázatkezelési stratégiák révén biztosítják a biztonságot. A kutatás részeként elvégzett kísérleti vizsgálatok validálják a javasolt biztonsági intézkedések hatékonyságát, és bizonyítják alkalmazhatóságukat valós technológiai környezetben.

Összefoglalva, a munka értékes betekintést nyújt a robotika és a biztonság metszéspontjaiba a védelmi iparban. A robothegesztési alkalmazásokhoz kapcsolódó kritikus biztonsági problémák kezelésével a disszertáció eredményei hozzájárulnak a munkavállalók egészségét és a működési hatékonyságot egyaránt előtérbe helyező ipari gyakorlatok fejlesztéséhez.

1 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.

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.

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 (Figure 1) [1].

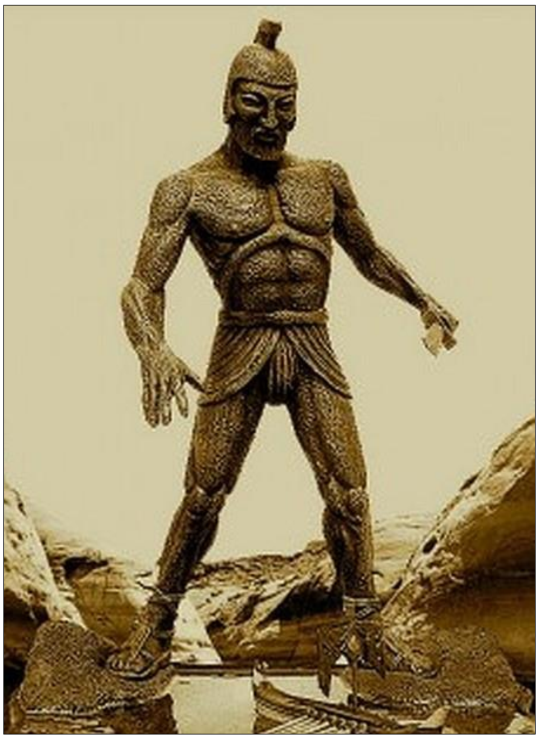

Figure 1 Talos, the gian robot of Hellas [1].

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 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 [7][8][9] :

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.

3.1 Qualitative Methods

Qualitative research is a method of inquiry that seeks to understand human behavior, experiences, and social phenomena in their natural context. Unlike quantitative research, which focuses on numerical data and statistical analysis, qualitative research emphasizes words, themes, and concepts, aiming to provide a deeper understanding of the subject matter.

The core characteristics of qualitative research include:

1. **Exploratory Nature**: Qualitative research is often used when exploring a new area where little is known or when the researcher wants to understand a phenomenon from the perspective of the participants.
2. **Subjective Data**: It involves collecting non-numerical data, such as interviews, observations, and textual analysis, which are then analyzed for patterns, themes, and insights.

3. **Flexibility**: Qualitative research is usually flexible and can evolve as the study progresses. This allows the researcher to adjust methods or questions based on emerging findings.
4. **Contextual Understanding**: Researchers aim to understand the phenomenon within its natural setting, considering the social, cultural, and environmental factors that may influence it.
5. **Inductive Approach**: The research process is typically inductive, meaning that researchers gather data and develop theories or hypotheses based on that data rather than starting with a hypothesis to test.

Data Collection Methods

Common methods of data collection in qualitative research include:

- **Interviews**: These can be structured, semi-structured, or unstructured and provide deep insights into the experiences and perspectives of participants.
- **Focus Groups**: A small group discussion where participants share their views on a particular topic, providing a rich source of data.
- **Observations**: Researchers observe participants in their natural environment to gather insights into their behaviors and interactions.
- **Content Analysis**: This involves analyzing texts, documents, media, or other forms of communication to uncover themes and meanings.

Data Analysis

Qualitative data analysis involves organizing and interpreting the collected data to identify patterns and themes. Common techniques include:

- **Coding**: Labeling portions of the data with codes that represent specific themes or concepts.
- **Thematic Analysis**: Identifying and analyzing recurring themes or patterns in the data.
- **Narrative Analysis**: Examining stories or personal accounts to understand how individuals make sense of their experiences.

Strengths of Qualitative Research

- Provides deep, detailed, and rich data.
- Offers a holistic understanding of the subject matter.
- Allows for flexibility and adaptation as the research progresses.

Limitations of Qualitative Research

- Findings may not be easily generalized to larger populations.
- It can be time-consuming and resource-intensive.
- Subjectivity in data collection and analysis can introduce bias.

Qualitative research is often used in fields such as psychology, sociology, education, anthropology, and healthcare to explore complex issues and gain insights that may not be captured through quantitative methods.

I conducted a review of practical experiences and case studies using the qualitative research method. Case studies of welding have highlighted the importance of the adverse health effects of welding [10][11][12][13][14]. I have explored different theories and synthesised them in my research ont he base of several literature.

3.2 Quantitative method

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.

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.

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.

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.

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

3.3 Research plan

In the beginning of the research I determined a research plan to define the step of my work. I followed the reserch plan, which was dinamically corrected continuously on the bease of the literature and the experimental results. The research plan was made together in harmony with my research goal.

1. Literature research

First step of the research, collection of the most relevant literature to be informed about the characteristics and hazards of GMAW technology and the health and safety regulations that apply to GMAW technology.

2. Summarizing and analyzing of the GMAW technology risks

The mostly researched and published risk is the robotic GMAW process established fume and it's health effects. The other risk like the robot movement is fmonitored by the robot programmers during the process automtization. The risk of the heat and spattering also well known and publisherd. Between the radiations the electromagnetic radiation is tested but the UV radiation level determination is less highly focused.

3. Overview of standards and limits for UV radiation hazards

My hypothese that the UV risk of the GMAW can identify as an dangerous health risk. The collection of the standards and regulations for the UV radiation hazards are the base of the most important knowledge for the risk assasement of UV.

4. Risk assassement

Among the risks arising from the GMAW technology, it was necessary to determine which health hazards require the greatest distance from the emitting source. The determination should be made by risk analysis based on the literature and experience gathered.

5. Experiments to determine UV radiation level

In addition to the results from the literature, real measurement results should be established. I had to check that other researchers' measurements were real and take measurements to own my own results.

6. Analysis and evaluation of the experimental results

Identify results based on own and literature data.

3.4 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.

4 New scientific results

Claim 1. In the case of GMAW technology, the danger zone can be defined by the UV radiation dangerous limit level if the length of the robot arm is less than the length of the UV radiation danger zone [15][16][17]**.**

The UV light as a function of UV level and the exposition time can cause conjunctivitis or vision impairment [18] [19] [20]. 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 [21] [22]. During arc welding, the visible light is very strong and the eyes can not be able to adapt to it.

> **Claim 2. The correct safety distance determination needs to take into account the actual UV level, which can't be more than the daily highest value one person has, which is 3 mW/cm^2. The safety distance can't be smaller than the robot arm length** [15][16][23]**.**

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 [24]. 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** [15][16][25][26]**.**

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 a danger zone around the welding. Collaborative robots can be used without physical barriers only when the danger zone is defined, and the crossing people are held outside** [15][16][26][27]**.**

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 low enough 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). In this case the robot's maximal arm reach A_L (m) is smaller or equal with the safe light distance L_{UV} (m) (6.1).

$$A_L \leq L_{UV} \tag{6.1}$$

$$D_D=2\cdot(A_L+L_{UV}+L_S) \text{ (m)} \tag{6.2}$$

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).

$$D_A=D_D+ 2\cdot(v_H\cdot t_R+L_{S2}) \text{ (m)} \tag{6.3}$$

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).

$$D_E=D_A+2\cdot L_{S3} \text{ (m)} \tag{6.4}$$

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.

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.

5 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.

6 References

[1] W. & M. contributor Adrienne Mayor, “The World’s First Robot: Talos.” [Online]. Available: https://www.wondersandmarvels.com/2012/03/the-worlds-first-robot-,talos.html

[2] D. HERNANDEZ, “500 Years Later, da Vinci’s Mechanical Lion Is Brought to Life,” no. SEP 19, 1:23 PM EST, 2019, Accessed: Feb. 16, 2024. [Online]. Available: https://www.popularmechanics.com/technolo- gy/a29020685/leonardo-da-vinci-mechanical-li- on-display/ (accessed on: 16 February 2024).

[3] J. F. Engelberger, “A tribute to Joseph Engelberger,” 2015. Accessed: Feb. 16, 2024. [Online]. Available: https://www.automate.org/robotics/engelberger/tribute-to-joseph-engelberger

[4] S. Kou, “Welding Metallurgy,” *New Jersey, USA*, vol. 431, no. 446, pp. 223--225, 2003, doi: 10.1557/mrs2003.197.

[5] W. S. D.H. Phillips, John Wiley & Sons, Ltd, *Welding engineering an introduction*. 2016. [Online]. Available: https://books.google.hu/books/about/Welding_Engineering.html?id=3RixngEACAAJ&redir_esc=y

[6] C. M. Schlick, *Industrial Engineering and Ergonomics*. 2009. doi: 10.1007/978-3-642-01293-8.

[7] J. D. Creswell, J. W., & Creswell, “Research Design: Qualitative, Quantitative, and Mixed Methods Approaches,” *SAGE Publ.*, 2017, Accessed: Jul. 18, 2024. [Online]. Available: http://www.ceil-conicet.gov.ar/wp-content/uploads/2015/10/Creswell-Cap-10.pdf

[8] R. K. Yin, “Case Study Research and Applications Design and Methods (6th ed.). Thousand Oaks, CA Sage.,” Scientific Research Publishing.

[9] Y. & G. E. Lincoln, “Naturalistic Inquiry. SAGE Publications.,” *SAGE Publ.*, 1985.

[10] N. Guha *et al.*, “Carcinogenicity of welding, molybdenum trioxide, and indium tin oxide,” *Lancet Oncol.*, vol. 18, no. 5, pp. 581–582, 2017, doi: 10.1016/S1470-2045(17)30255-3.

[11] T. D. Tenkate, “Ocular ultraviolet radiation exposure of welders,” *Scandinavian Journal of Work, Environment and Health*, vol. 43, no. 3. 2017. doi: 10.5271/sjweh.3630.

[12] K. N. Heltoft, R. M. Slagor, T. Agner, and J. P. Bonde, “Metal arc welding and the risk of skin cancer,” *Int. Arch. Occup. Environ. Health*, vol. 90, no. 8, 2017, doi: 10.1007/s00420-017-1248-5.

[13] G. . Liss, “Health effects of welding and cutting fume- an update,” *Occup. Dis. Panel*, p. pp.1–151, 1996, [Online]. Available: http://www.canoshweb.org/odp/html/rp5.htm.

[14] S. S. Siew, T. Kauppinen, P. Kyyrönen, P. Heikkilä, and E. Pukkala, “Exposure to iron and welding fumes and the risk of lung cancer,” *Scand. J. Work. Environ. Heal.*, vol. 34, no. 6, 2008, doi: 10.5271/sjweh.1296.

[15] M. Schramkó, A. Kafi, L. Gyura, and T. A. Kovács, “An Experimental Study of the Gas Metal Arc Welding Ultraviolet Effect as a Function of the Distance,” in *Lecture Notes in Mechanical Engineering*, 2023. doi: 10.1007/978-3-031-15211-5_76.

[16] A. Kafi, Z. Nyikes, and T. A. Kovács, *Collaborative robot applicability analysis on the place of the manual welder*. Proceedings of the 10th International Conference on Applied Internet and Information Technologies AIIT 2020 Zrenjanin, Serbia, 2020.

[17] A. Kafi, Z. Nyikes, M. Schramkó, and T. A. Kovács, “Arc welding safety zones determination as a function of the UV radiation,” in *Journal of Physics: Conference Series*, 2022. doi: 10.1088/1742-6596/2315/1/012029.

[18] E. Otokpa and Y. B. Usman, “An Assessment of Ultraviolet Radiation Components of Light Emitted From Electric Arc and Their Possible Exposure Risks,” *Glob. J. Pure Appl. Sci.*, vol. 19, pp. 145–149, 2013, Accessed: Feb. 16, 2024. [Online]. Available: file:///C:/Users/Abdallah Kafi/Downloads/ajol-file-journals_87_articles_118658_submission_proof_118658-1033-327916-1-10-20150624.pdf

[19] G. Horneck, “Quantification of biological effective environmental UV irradiance,” *Adv. Sp. Res.*, vol. 26, no. 12, 2000, doi: 10.1016/S0273-1177(00)00172-1.

[20] L. M. Falcone and P. C. Zeidler-Erdely, “Skin cancer and welding,” *Clinical and Experimental Dermatology*, vol. 44, no. 2. 2019. doi: 10.1111/ced.13783.

[21] A. J. Dixon and B. F. Dixon, “Ultraviolet radiation from welding and possible risk of skin and ocular malignancy,” *Med. J. Aust.*, vol. 181, no. 3, 2004, doi: 10.5694/j.1326-5377.2004.tb06207.x.

[22] V. I. Vishnyakov, S. A. Kiro, and A. A. Ennan, “Reducing of UV Radiation Intensity, Ozone Concentration and Fume Formation in Gas Metal Arc Welding,” *Aerosol Sci. Eng.*, vol. 4, no. 3, 2020, doi: 10.1007/s41810-020-00066-2.

[23] M. Schramkó, A. Kafi, and T. A. Kovács, “Analysis of the Harmful Effects of UV Radiation Generated During Welding,” *Acta Mater. Transylvanica*, vol. 5, no. 2, 2022, doi: 10.33924/amt-2022-02-08.

[24] J. Takahashi, H. Nakashima, N. Fujii, and T. Okuno, “Comprehensive analysis of hazard of ultraviolet radiation emitted during arc welding of cast iron,” *J. Occup. Health*, vol. 62, no. 1, 2020, doi: 10.1002/1348-9585.12091.

[25] A. Kafi, T. A. Kovács, L. Tóth, and Z. Nyikes, “Robots Application for Welding,” *Műszaki Tudományos Közlemények*, vol. 12, no. 1, 2020, doi: 10.33894/mtk-2020.12.07.

[26] A. Kafi, T. A. Kovács, and Z. Nyikes, “Robots in the Industry 4.0,” in *NATO Science for Peace and Security Series C: Environmental Security*, 2022. doi: 10.1007/978-94-024-2174-3_31.

[27] A. Kafi and T. A. Kovács, “Arc Sensor Parameter Optimisation for Robot Welding,” in *Lecture Notes in Mechanical Engineering*, 2021. doi: 10.1007/978-981-15-9529-5_44.

Publication list of the author

1 A. Kafi, T. A. Kovács, and Z. Nyikes, “Robots in the Industry 4.0,” in *NATO Science for Peace and Security Series C: Environmental Security*, 2022. doi: 10.1007/978-94-024-2174-3_31.

2 M. Schramkó, A. Kafi, and T. A. Kovács, “Analysis of the Harmful Effects of UV Radiation Generated During Welding,” *Acta Mater. Transylvanica*, vol. 5, no. 2, 2022, doi: 10.33924/amt-2022-02-08.

3 A. Kafi, Z. Nyikes, M. Schramkó, and T. A. Kovács, “Arc welding safety zones determination as a function of the UV radiation,” in *Journal of Physics: Conference Series*, 2022. doi: 10.1088/1742-6596/2315/1/012029.

4 A. Kafi, T. A. Kovács, L. Tóth, and Z. Nyikes, “Robots Application for Welding,” *Műszaki Tudományos Közlemények*, vol. 12, no. 1, 2020, doi: 10.33894/mtk-2020.12.07.

5 M. Schramkó, A. Kafi, L. Gyura, and T. A. Kovács, “An Experimental Study of the Gas Metal Arc Welding Ultraviolet Effect as a Function of the Distance,” in *Lecture Notes in Mechanical Engineering*, 2023. doi: 10.1007/978-3-031-15211-5_76.

6 A. Kafi, Z. Nyikes, and T. A. Kovács, *Collaborative robot applicability analysis on the place of the manual welder*. Proceedings of the 10th International Conference on Applied Internet and Information Technologies AIIT 2020 Zrenjanin, Serbia, 2020.

7 A. Kafi and T. A. Kovács, “Arc Sensor Parameter Optimisation for Robot Welding,” in *Lecture Notes in Mechanical Engineering*, 2021. doi: 10.1007/978-981-15-9529-5_44.