TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 23, Issue Special I, September, 2023

INTEGRATION OF COLLABORATIVE ROBOTS IN THE AUTOMOTIVE INDUSTRY DURING POST-PANDEMIC RECOVERY

Aurel - Mihail ȚÎȚU, Vasile GUSAN, Mihai DRAGOMIR

Abstract: *In the era of speed and technological advancement, the automotive industry has faced various crises, pandemics, and catastrophes. Following the global financial crisis of 2008, also known as the Great Recession, the industry was forced to confront the COVID-19 pandemic, and now the entire market is directly facing the semiconductor crisis. Globally, there have been and will certainly be crises regarding human resources, and situations in which global industrial organizations in the automotive sector will face challenges and must implement solutions to optimize their costs to ensure profitability even in times of crisis. In the current conditions, the authors argue that only industrial organizations that are oriented towards flexibility and openness to adaptability will be able to successfully survive. In this context, collaborative robots are becoming an increasingly viable alternative. In this scientific work, the authors propose a pragmatic vision regarding the integration of collaborative robots, emphasizing the importance of an effective integration process of collaborative robots in organizations within the automotive industry. The authors consider this proposed desideratum an important aspect, as collaborative robots are considered universal and highly flexible tools that can easily adapt to any process.*
Key words: *collaborative robots, automation, management, integration, post-pandemic.*

1. INTRODUCTION

The automotive world has gone through multiple crises over time. The most recent crisis they went through was the global financial crisis of 2008, known as the Great Recession, following the COVID-19 pandemic, and now facing the full force of the semiconductor crisis. Also, the appearance of electric cars shook the entire industry to its foundations, forcing it to adapt and offer the market new solutions that are much more environmentally friendly, digitally interconnected and innovative.

The human inclination towards innovation has led to the development of collaborative robots in the 21st century.

Collaborative robots are designed to perform tasks alongside human workers, in the same workspace as their colleagues, providing greater mobility and flexibility. [1]

Collaborative robots represent a remarkable technological innovation in the field of robotics, designed by humans to promote collaboration between humans and robots.

Although the adoption of collaborative robots in production processes is an insufficiently researched topic in the academic area [2], they are already integrated and used in the private sector, to improve efficiency and productivity in the manufacturing flow, and contribute to the reduction of time and costs of production.

In the private sector, the use of collaborative robots in the manufacturing process is a technological innovation that has been successfully adopted to improve the manufacturing process, increase its efficiency and effectiveness, as well as reduce time.

In addition to the mentioned aspects, collaborative robots also contribute to the optimization of production costs. [3-5]

By implementing collaborative robots, the quality of the manufacturing process is improved, ensuring a more efficient and effective production. [6]

Taking into account the aspects mentioned, in this scientific paper, the authors propose a pragmatic approach for integrating collaborative robots in the automotive industry, emphasizing the importance of an efficient integration process.

2. MANUFACTURING PROCESSES WITH COLLABORATIVE ROBOTS

The use of collaborative robots in manufacturing processes is increasingly common in the industry, and the context of the COVID-19 pandemic has further facilitated the implementation of these types of robots.

As a result of the COVID-19 pandemic, there has been a significant increase in the implementation of collaborative robots. This can be attributed to several reasons, including:

- Collaborative robots cannot contract and transmit the virus;
- Cobots do not require time off, whether for vacation or sick leave;
- Collaborative robots do not need rest or meal breaks;
- Their maintenance is close to zero.

Collaborative robots are mechanical devices designed in the form of robotic arms, equipped with joints similar to those of humans, which facilitate their movement.

Generally, they are composed of 6 axes and resemble articulated industrial robots. Due to their ability to share the work environment with humans, they are called collaborative robots, also known as "cobots". [7-10]

Integrating collaborative robots into manufacturing processes presents the advantage of increased efficiency and effectiveness. This is because collaborative robots are capable of maintaining the same speed and precision as humans. An efficient manufacturing process produces maximum speed and performance, while an effective manufacturing process produces a high number of quality products. Collaborative robots can be integrated into any production area for:

- Parts or finished product handling;
- Screwdriving;
- Grinding;
- Injection of plastic materials;
- Dispensing of paste onto products.

Manufacturing processes in which collaborative robots have been implemented have higher productivity, a significantly better result in terms of part quality, and much better ergonomics.

After implementation, collaborative robots can improve productivity until a technological or testing process becomes the bottleneck of the manufacturing flow. If in the past the operator represented the bottleneck in the manufacturing flow, hypothetically performing all the necessary movements in 20 seconds, when replaced with a collaborative robot, the time can be reduced to the highest cycle time of an existing technological process on the flow, which hypothetically, in this case, could be 12 seconds. Also, collaborative robots can work continuously 24/7 without getting tired, stopping, or requiring a break.

Collaborative robots will also improve the quality of the manufacturing process. A high-quality manufacturing process will produce high-quality products. Thanks to very good repeatability of ± 0.01 mm - ± 3 mm [11], it can be said that collaborative robots have very good precision, comparable even to stationary industrial robots.

Repeatability represents the maximum deviation of the robot after 100 movements from the coordinate that was previously set. Thus, it can be concluded that collaborative robots can be integrated into numerous manufacturing processes such as screwing, grinding, pick-and-place, paste dispensing, and many more. Multiple rejects due to the human worker in the past will disappear completely. Thanks to this aspect, the number of compliant products will increase considerably.

Ergonomics is also an important criterion regarding the operator's workplace. A workplace with good ergonomics will not lead to premature worker fatigue or injury over time.

Replaced operators will be able to take on jobs that have a positive impact on product quality. The only jobs that collaborative robots will take over are those with repetitive, ergonomically poor, and tedious characteristics. Certainly, jobs taken over by robots will be easily relinquished by humans.

3. THE PROCESS OF INTEGRATING COLLABORATIVE ROBOTS

The integration of collaborative robots is a process that is relatively simple and quick. For the process to be carried out efficiently and effectively, the number of resources and documentation on these types of robots must be properly done.

The process of integrating collaborative robots is divided into several sequential processes that must be followed:

- The process of studying the feasibility of integrating collaborative robots;
- The procurement process;
- The assembly and programming process;
- The validation process of the manufacturing process with collaborative robots;
- The launch process into the mass production of the new flow with collaborative robots.

Following the completion of the study, technical documentation is drawn up for the organization of the procurement process. This procedure is also part of the feasibility study process.

The procurement process is based on the requirements specified in the technical documentation and the existing list of needs. In case several suppliers are offering similar technical solutions that meet the technical conditions, a bidding process will be organized among them. In this case, the bidding process could be organized as follows:

- A bidding process between collaborative robot suppliers (Universal Robots, Techman, Doosan, Kuka);
- A bidding process between gripper suppliers (Schunk, Weiss, Festo, etc.);
- A bidding process between safety equipment suppliers (Sick, Pilz, etc.).

In this bidding process, the participation conditions for each supplier are communicated through the specifications/technical requirements document, which may include:

- Requirements of technical nature, aspects which are included in the specification sheet;
- Requirements regarding delivery time;
- Requirements regarding payment terms.

Based on the participation conditions, a decision is made, taking into account all the relevant criteria. If all suppliers meet the participation conditions, they enter into a negotiation process. If they do not meet the project requirements, they will be disqualified.

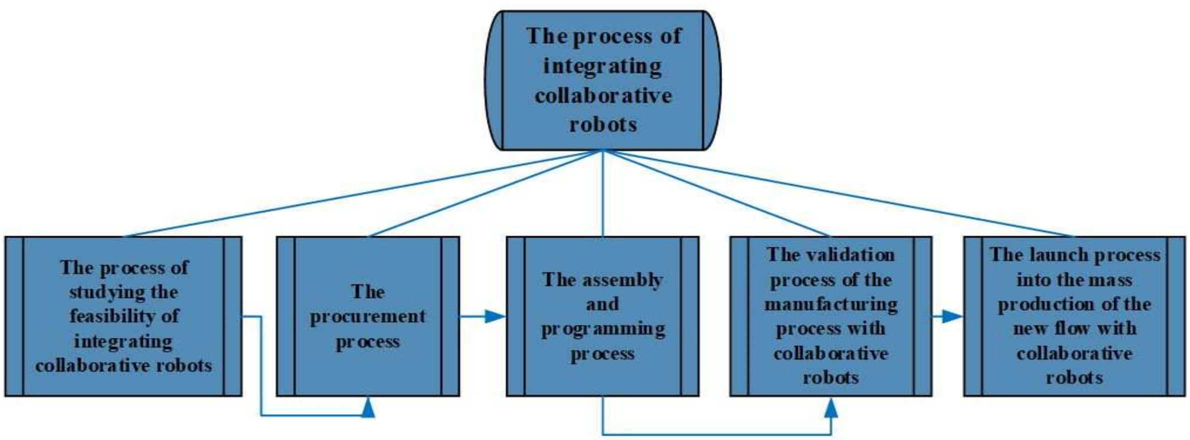

Fig. 1. The process of integrating collaborative robots

Firstly, it is necessary to initiate a feasibility study process for the manufacturing process to integrate collaborative robots. During this study, the assembly method for robots, the number of grippers, the need for scanners or safety barriers, if applicable, and the establishment of communication modes between collaborative robots and the surrounding environment are determined. Based on this study, the cycle time and the number of robots required for the application in which they need to be integrated will also be determined.

The final decision is made after negotiations, based on a decision-making matrix. Upon declaring the winning bidders of the tender, a firm order for the offered items can be placed.

The procurement process is completed upon receipt of the ordered items, order invoicing, and payment.

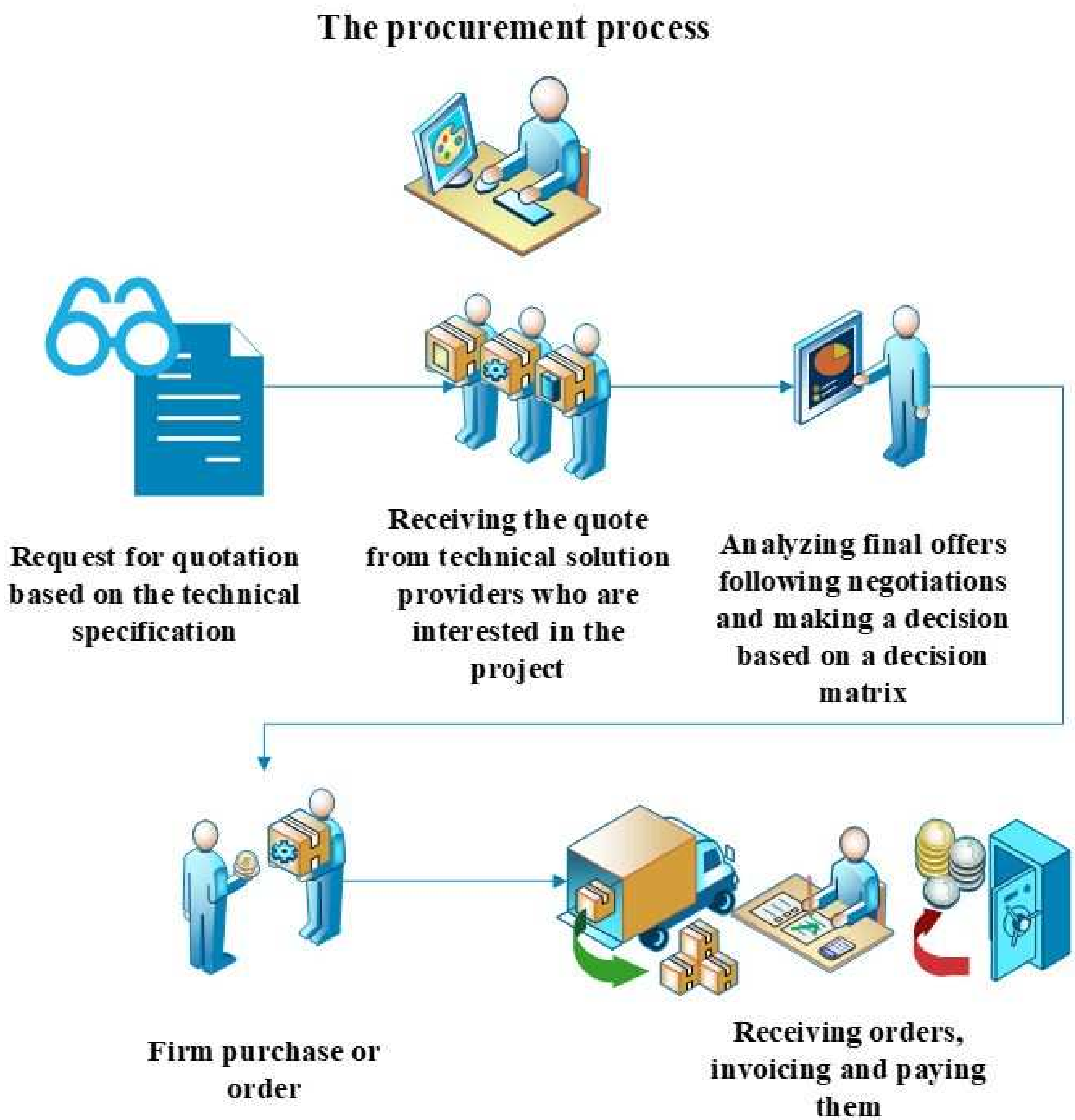

Fig. 2. The procurement process

The assembly and programming process can begin upon receipt of the ordered items, depending on the availability of the manufacturing process. If the production flow needs to be tailored to the customer, assembly and programming activities are planned on the production flow so that production is not affected and the customer is satisfied with the orders received. Customer satisfaction must always remain a top priority.

The collaborative robot structure, collaborative robots, corresponding grippers, and, where appropriate, certain mechanical and electrical safety devices are sequentially mounted. All devices and equipment are connected to the collaborative robots to ensure their communication with the surrounding environment.

Collaborative robots are capable of communication through various means:

- Electrical inputs and outputs;
- Modbus industrial protocol;
- TCP-IP industrial protocol;

- Profinet industrial protocol.

Due to the requirement for digitalization, nowadays, industrial communication protocols based on ethernet connection are generally preferred. If the robot is introduced into the network, it can be remotely connected to using a laptop or computer utilizing its allocated IP. Another benefit is that automatic backups of calibration files and collaborative robot programs can be made at certain intervals. Finally, the most important argument is cable management.

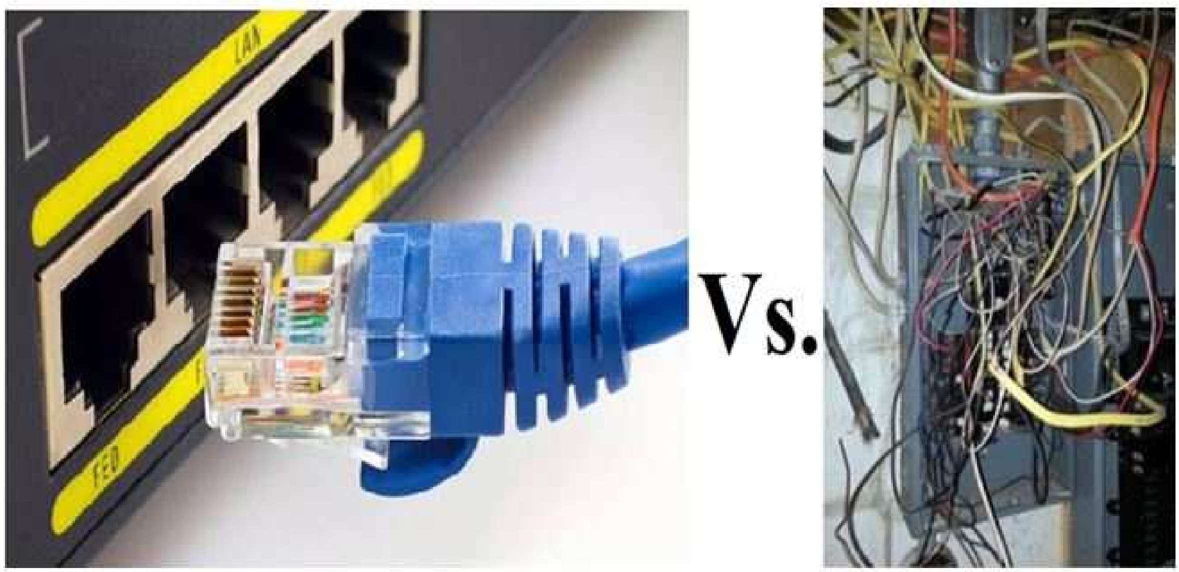

Fig. 3. Using ethernet cable vs. cables

It will always be much easier to use an Ethernet cable for the entire communication than a bunch of electrical wires or cables. A concrete example can be seen in Figure 3.

Once the electrical and mechanical assembly has been completed and the connection between collaborative robots and the surrounding environment has been established, collaborative robot programming can begin.

Certain standard steps must be followed for each basic setup of any application:

- Determining and declaring the centre point of the tool;
- Declaring the mounting position;
- Declaring, if applicable, the inputs and outputs, signals, and respective variables;
- Saving the basic configurations.

After setting up these basic settings, the actual programming of the collaborative robot can begin. The program will be run sequentially from top to bottom. Each input will be queried, and each output will be started and stopped accordingly. Based on these, decision and logic gates can be constructed, and the collaborative robot can make decisions using simple if/else-if/else functions. The robot's movements can also be defined together with the coordinate configuration for each point. For each movement/point, the speeds of the collaborative robot can be defined, including their deceleration during the program. To prevent the robot from stopping at each point, it can be bypassed with a certain radius defined by the programmer. In this case, the robot will no longer decelerate and will maintain its speed until the next point where it needs to stop. The possibilities for programming and developing applications are unlimited, but they must ultimately adhere to the specifications and be developed as simply as possible.

The validation process of the manufacturing flow with robots represents the certification of the functionality of the new manufacturing process. For this aspect, the manufacturing flow must be re-qualified by the departments responsible for this aspect. For example, in the automotive electronics industry, measurements are taken from an ESD point of view, and if the measurements are good, ESD certification will be obtained. ESD comes from Electrostatic

Safety Discharge. Therefore, it is important for collaborative robots to be made of materials that favor electrostatic discharge. Work instructions will need to be updated to include the new way of working with collaborative robots so that the operator is familiarized with them. The line will be re-validated from a safety standpoint with collaborative robots by an occupational health and safety specialist. During this re-validation, the emergency button functionality and the functionality of the safety auxiliary elements connected to the collaborative robot will also be checked. Following this re-validation, a certification will be obtained from the HSE auditor certifying that the manufacturing flow with collaborative robots is safe to be operated by workers.

Additionally, certain qualitative tests will be performed regarding the influence of the collaborative robot on the product. Thus, if the gripper of the collaborative robot comes into direct contact with the electronic board, it will be subjected to stress tests to demonstrate that the product will not suffer qualitatively as a result of its manipulation by the robot. Reports will be generated from these tests and will be transmitted to the internal auditor and the client if requested.

Following the obtaining of all certifications, and completion of necessary tests and documentation, an internal qualitative audit is carried out to revalidate the collaborative robot flow. During the audit, the performance of the collaborative robot flow is monitored in terms of capacity, downtime, and functionality. The obtained certifications, documentation, and reports that were carried out are verified as well.

The series launch is carried out following receipt of confirmation from the customer to carry out this action. After the internal quality audit for revalidation of the collaborative robot manufacturing flow is completed, a report is prepared in which, as appropriate, feasible actions with deadlines for implementation are opened. After the actions are closed, this report is transmitted to the customer together with the presentation of the improvements made, the certifications and the reports carried out to receive confirmation from the customer. Until the confirmation is received, if the organization decides that it can produce with collaborative robots, the parts produced from the collaborative robot manufacturing flow will be manufactured at the organization's own risk and will be blocked until confirmation is received from the customer. Following acceptance received from the customer, products manufactured in this manufacturing flow can be delivered to the customer, and the collaborative robot manufacturing flow can enter into serial production and be delivered directly to the customer.

4. RECEIVING THE COLLABORATIVE ROBOT: AN EXPLORATION OF BENEFITS AND FEATURES UPON ORDERING

The company Universal Robots spearheaded the introduction of collaborative robots in the market. However, due to the surge in demand, other competitors such as Techman Robots, ABB Robotics, Doosan Robotics, Kuka, and others emerged offering similar solutions.

Given Universal Robots' pioneering position, we sought to explore what they provide when purchasing a collaborative robot. The collaborative robot provided by Universal Robots is delivered in two packages, as illustrated in Fig. 4:

- Package One contains the articulated robot arm.
- Package Two includes the control box, equipped with a control tablet, power cables, tablet mounting brackets, a UR laser pen, the robot manual, and documents certifying product quality and calibration.

The robotic arm can be quickly connected to the control box through a power cable, and the control box is powered by 230V AC current. The collaborative robotic arm has 6 available axes of motion (6 joints, as shown in figure 5), composed of human-arm-like joints based on a modular design. Each joint can rotate up to +/- 360°. An exception, however, is found in the UR3 cobot, which can rotate its joint infinitely without such a constraint.

The control box and the touchscreen tablet, are interconnected via a non-detachable cable, which internally houses: the robot's software

Fig. 4. Collaborative robot delivery box [12]

USB, peripheral inputs and outputs for sensors, power supply, safety devices, and connection with the robotic arm.

The touchscreen tablet features an emergency stop button, a power button, a button to release the robot's axis brakes, and a peripheral input for USB through which program backups, loading new programs into the robot's memory, information extraction, and other functionalities can typically be performed. The collaborative robot's programming and control are conducted through this tablet interface.

The control box corresponds to each cobot type based on its series. The collaborative robot's control box contains multiple dedicated connectors for inputs and outputs. Specifically, the control box features the following connectors,: an emergency stop connector, a temporary stop connector, a remote control connector for starting and stopping the cobot, two connectors with configurable inputs, two connectors with configurable outputs for safety devices, two connectors for inputs totaling 8 digital inputs, two connectors for outputs totaling 8 digital outputs, and finally, two connectors for analog inputs and outputs, totaling two analog inputs and two analog outputs with a voltage range adjustable between 0 and 10V DC and a current range adjustable between 4 to 20 mA.

To enable the robot's functionality without safety devices, the inputs for safety devices are bypassed. There are two connectors for safety devices because the electrical connections for safety devices, such as safety buttons and perimeter scanners, are made on two channels.

Additionally, near the mechanical flange of each robot, there is an eight-pin output connector intended for various command applications, including grippers, industrial vision systems, and more.

Each input or output can be renamed so that any technician accessing this menu can observe their respective status. For example, input zero can be renamed as sensor signal 1. This significantly aids technical personnel during collaborative robot troubleshooting.

Access to the robot's program can be password-protected to ensure that only authorized technical personnel can access it.

Several selection criteria exist to choose the appropriate robot for a given application. These criteria depend on the intended use of the collaborative robot and the mechanical constraints it must adhere to.

For instance, if the application requires a small workspace, under 500 mm, and involves manipulating objects weighing less than 2 kg, the optimal choice is UR3. Although the weight limit of the UR3 robot is 3 kg, the gripper that will handle the parts is considered to weigh one kilogram in this scenario. If the application involves a medium-sized workspace, under 850 mm, and manipulating objects weighing less than 4 kg, the ideal choice in this case is UR5. Similar selection criteria will be applied to the other robots.

Fig. 5. Collaborative robot joints [12]

Budget is also a crucial criterion that must be taken into account. When estimating the project budget, certain auxiliary elements required for application operation, such as robot support, gripper, and safety equipment, must also be considered. Clearly defining these criteria will lead to a significant reduction in implementation costs.

5. CONCLUSIONS

In this comprehensive scientific investigation, it has been unequivocally demonstrated that the integration of collaborative robots into manufacturing workflows can yield exponential improvements in efficiency and effectiveness. These tangible enhancements extend beyond mere conjecture and have a direct and substantial impact on critical aspects of industrial production, including product quality, overall productivity, and the optimization of workplace ergonomics.

The study meticulously examined the intricate process of integrating collaborative robots, revealing their inherent complexity and extensive nature. Despite the concise presentation offered here, the process comprises a series of interdependent subprocesses that demand rigorous adherence and sequential execution to ensure a seamless and successful implementation of collaborative robot integration. Each subprocess involves meticulous planning, configuration, and calibration, making the integration process both a challenging and rewarding endeavour.

Throughout this research, the advantages of incorporating collaborative robots into manufacturing workflows were consistently underscored and substantiated based on the author's practical experiences. As the manufacturing landscape rapidly evolves, the adoption of collaborative robotics offers invaluable benefits, including increased precision, reduced production cycle times, minimized downtime, and enhanced adaptability to evolving industry demands.

It is crucial to acknowledge that the process of integrating collaborative robots should not be seen as a replacement for human labour but rather as a symbiotic relationship between humans and robots. Emphasizing the need for human-robot collaboration, this research advocates for a harmonious coexistence in which both entities complement each other's strengths to achieve shared production and efficiency objectives. Consequently, personnel must be actively involved in decision-making processes regarding collaborative robot integration and be equipped with specialized training to collaborate effectively, efficiently, and safely with these robotic counterparts.

In further scrutinizing the integration process, it became evident that thorough planning and exhaustive analysis are paramount to ensuring optimal outcomes. Environmental requirements, workplace safety protocols, technical capabilities of the robots, personnel training needs, and strict compliance with quality and environmental standards are crucial considerations in laying a solid foundation for successful implementation.

Throughout this exploration, the spotlight was cast upon Universal Robots, a trailblazer and pioneer in the collaborative robot market. Universal Robots' innovative solutions have played a catalytic role in spearheading the widespread adoption of collaborative robotic technology. The company's collaborative robot offerings have garnered immense popularity, eliciting a competitive response from other prominent players in the industry such as Techman Robots, ABB Robotics, Doosan Robotics, Kuka, and several others.

In addition to their pivotal role in collaborative robot integration, the control box and touchscreen tablet were unveiled as indispensable components of the robotic system. The control box, bespoke for each cobot series, houses an array of connectors exclusively designated for inputs and outputs. These connectors enable a myriad of functionalities, including crucial safety features such as emergency stops, temporary stops, and remote control, as well as facilitating digital and analogue inputs and outputs. The ability to customize and rename inputs and outputs represents a valuable asset in expediting technical troubleshooting and fine-tuning the collaborative robot's behaviour in diverse manufacturing scenarios.

The advantages of collaborative robots extend beyond traditional manufacturing settings and permeate into diverse sectors such as healthcare, logistics, agriculture, and even space exploration. Their versatility and adaptability make them ideal candidates for solving real-world challenges and addressing societal needs, making them key contributors to global progress.

In conclusion, this seminal scientific study sheds light on the vast potential of collaborative robots to revolutionize modern industrial practices. The findings underscore the transformative impact of integrating collaborative robots into manufacturing workflows and the immense value they bring in terms of efficiency, productivity, and workplace optimization. As the field of collaborative robotics continues to evolve, it is poised to shape the future of industrial automation, ushering in a new era of advanced manufacturing processes across diverse sectors. The profound implications of this research serve as a clarion call for embracing and harnessing the power of collaborative robots as catalysts for continued progress and innovation in the realms of manufacturing and beyond.

6. REFERENCES

[1] Sherwani, F., Asad, M. M., Ibrahim, B. S. K. K., *Collaborative Robots and Industrial Revolution 4.0 (IR 4.0)*, 2020 International Conference on Emerging Trends in Smart Technologies (ICETST), Karachi, Pakistan, pp. 1-5, 2020, doi: https://doi.org/10.1109/ICETST49965.2020.9080724

[2] Simões, A. C., Soares, A. L., & Barros, A. C., *Factors influencing the intention of managers to adopt collaborative robots (cobots) in manufacturing organizations*. Journal of engineering and technology management, 57, 101574, (2020), doi: https://doi.org/10.1016/j.jengtecman.2020.101574

[3] Benotsmane, R.; Kovács, G.; Dudás, L. Economic, *Social Impacts and Operation of Smart Factories in Industry 4.0 Focusing on Simulation and Artificial Intelligence of Collaborating Robots*. Soc. Sci. 8, 143, (2019), doi: https://doi.org/10.3390/socsci8050143

[4] Gualtieri, L., Rauch, E., Vidoni, R. and Matt, D. T., *An evaluation methodology for the conversion of manual assembly systems into human-robot collaborative workcells*. Procedia Manufacturing, 38, 358-366, (2019), doi: https://doi.org/10.1016/j.promfg.2020.01.046

[5] Michaelis, J. E.; Siebert-Evenstone, A.; Shaffer, D. W. and Mutlu, B. *Collaborative or simply uncaged? understanding human-cobot interactions in automation.* In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1-12, (2020), doi: https://doi.org/10.1145/3313831.3376547

[6] Țîțu, A. M., & Gusan, V., *The Influence of Collaborative Robots on the Quality, Efficiency and Effectiveness of Automotive Manufacturing Flows*. In New Technologies, Development and Application V, Cham: Springer International Publishing, (2022), pp. 58-67, doi: https://doi.org/10.1007/978-3-031-05230-9_6

[7] Gusan, V., Țîțu, M. A., Oprean, C., *Industrial robots versus collaborative robots-The place and role in nonconventional technologies*. In ACTA Technica Napocensis-Series: Applied mathematics, mechanics, and engineering, 65(1S), pp. 101-110, (2022).

[8] Shirine, E.; Marei, M.; Weidong, L. and Zahid, U. *Cobot programming for collaborative industrial tasks: An overview. Robotics and Autonomous Systems*, Volume 116, pp. 162-180, (2019), doi: https://doi.org/10.1016/j.robot.2019.03.003

[9] Peshkin, M.; and Colgate J.E. *Cobots*, Industrial Robot, Vol. 26 No. 5, pp. 335-341, (1999), doi: https://doi.org/10.1108/01439919910283722

[10] Sordan, J. E.; Pimenta, M. L.; Oprime, P. C.; Rodrigues, Y. T. and Marinho, C. A. *Collaborative robotics: a literature overview from the perspective of production management*. Revista Produção E Desenvolvimento, 7, (2021), doi: https://doi.org/10.32358/rpd.2021.v7.516

[11] *Cobot Comparison Tool: Collaborative Robot Buyer's Guide*, Retrieved from Collaborative Robotics Trend - The essential guide for cobot end users, (2023, 04, 22).: https://www.cobottrends.com/cobot-comparison-tool/

[12] Universal Robots, (2016). *Universal Robots Core Training CB3*

Integrarea roboților colaborativi în industria auto în timpul recuperării post-pandemice

Rezumat: *În era vitezei și progresului tehnologic, industria auto s-a confruntat cu diverse crize, pandemii și catastrofe. În urma crizei financiare globale din 2008, cunoscută și sub numele de Marea Recesiune, industria a fost nevoită să se confrunte cu pandemia COVID-19, iar acum întreaga piață se confruntă direct cu criza semiconductorilor. La nivel global, au existat și vor fi cu siguranță crize în ceea ce privește resursele umane, și situații în care organizațiile industriale globale din sectorul auto se vor confrunta cu provocări și trebuie să implementeze soluții de optimizare a costurilor pentru a-și asigura profitabilitatea chiar și în perioade de criză. În condițiile actuale, autorii susțin că numai organizațiile industriale care sunt orientate spre flexibilitate și deschidere către adaptabilitate vor putea supraviețui cu succes. În acest context, roboții colaborativi devin o alternativă din ce în ce mai viabilă. În această lucrare științifică, autorii propun o viziune pragmatică privind integrarea roboților colaborativi, subliniind importanța unui proces eficient de integrare a roboților colaborativi în organizațiile din cadrul industriei auto. Autorii consideră acest deziderat propus un aspect important, întrucât roboții colaborativi sunt considerați instrumente universale și extrem de flexibile care se pot adapta cu ușurință oricărui proces.*
Keywords: *roboți colaborativi, automatizare, management, integrare, post-pandemic*

Aurel - Mihail ȚÎȚU, Professor, Corresponding Author, "Lucian Blaga" University of Sibiu, 10 Victoriei Street, Sibiu, Romania, e-mail: mihail.titu@ulbsibiu.ro; The Academy of Romanian Scientist, 3 Ilfov Street, Bucharest, Romania

Vasile GUSAN, Sc.D. Student, National University of Science and Technology POLITEHNICA Bucharest, Faculty of Industrial Engineering and Robotics, 313 Splaiul Independenţei, 6th District, Bucharest, Romania, e-mail: vasilegusan@yahoo.ro

Mihai DRAGOMIR, Professor, Technical University of Cluj-Napoca, Design Engineering and Robotics, bd. Muncii, no. 103-105, 400641 Cluj-Napoca, Romania, e-mail: mihai.dragomir@muri.utcluj.ro