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Industrial Applications of Collaborative Robots

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Abstract: With the advent of the Industry 4.0 era, the application of collaborative robots (cobots) in industrial fields has greatly increased. Intelligent collaborative robots or smart cobots enable high flexibility by combining the human ability to adapt to new tasks with automated robots (precision, repeatability) performance. This paper will analyze the current application status and usage of collaborative robots in the various industrial fields, and its benefits and disadvantages from the discussion. Firstly, this paper the defines collaborative robots and explains the difference between cobots and traditional industrial robots. Then, it analyzes the specific application cases of collaborative robots in automotive manufacturing, electronics and electrical appliances, food and beverage, pharmaceutical and chemical industries. Subsequently, this paper introduces the main technologies linked to collaborative robots, including sensors, Human-Robot Interaction (HRI), machine learning and safety technologies. Through the study of actual application cases, this paper summarizes the significant advantages of collaborative robots to improve productivity, reduce costs, and optimize the working environment. Meanwhile, this paper also discusses the current technical challenges, regulatory and standard issues as well as marketing difficulties for collaborative robots, and looks at future development trends and research directions. The results demonstrate that the utilization of collaborative robots in industry has a promising future and research and practical significance as well.

Keywords: Collaborative robots, human-robot interaction, sensors, machine learning.

1. Introduction

Since the global manufacturing business is developing continuously and technology is changing greatly, industrial automation has become a main factor in elevating the efficiency and competition of economic operations. The concept of collaborative robots, relatively recently developed but adopted by the vast majority of industries, has now taken over numerous sectors. Unlike the traditional industrial robots that are restricted to one function and lack adaptability, collaborative robots are safe to be in the vicinity, work hand in hand with workers, and increase productivity and working efficiency[1].

Collaborative robots can work well even as they perform repetitive tasks and are capable of working with maintain high accuracies, making them best suited for tasks in complex and changing work environments. Furthermore, the decentralized systems of these robots with advanced sensors and AI make them perfect in industries that have changing structures, which has ensured increased

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use in sectors such as automotive manufacturing, electronics and appliances, food and beverages, and pharmaceutical and chemicals. The introduction of collaborative robots helps organizations improve productivity and lower operational costs while at the same time improving the work environment and increasing employee safety and satisfaction.

However, although collaborative robots show great potential in industrial applications, the deployment and use of them is currently limited. Technical bottlenecks, lack of regulations and standards, and limitations in market acceptance are all important topics that need to be addressed today. Therefore, it is of great theoretical and practical significance to study in depth the current status, technological development and future trends of collaborative robots in industry.

This paper will comprehensively analyze the current status of the application of collaborative robots in industry and the benefits they bring by elaborating on the definition and characteristics of collaborative robots and combining them with specific industry application cases. In addition, this paper will discuss the collaborative robot development status and challenges and demonstrate the future development direction. It is hoped that this study will bring useful references and enlightenment on the subsequent research and practical application of collaborative robots in industry.

2. Definition and characteristics of collaborative robots

2.1. The definition of collaborative robots

Colgate firstly presented the definition of ‘cobot’: A robot device which manipulates objects in collaboration with a human operator.”

Collaborative robots, or cobots, have seen an evolution in understanding and definition in recent years. Cobots, recognized as a distinct breed of industrial robots with multiple degrees of freedom, usually 6-Axis, for tasks related to manufacturing, stand out from the conventional industrial robots as they operate in close proximity to people. In comparison with traditional industrial robots, they are more user-friendly, easily programmable and teachable, more flexible in use and place a high priority on human safety when working in collaboration. This collaboration workspace is defined as an “operating space in which a robot system (including any workpiece) and a human are in physical contact during normal production operation” [2].

2.2. Differences from traditional industrial robots

In light of the significant differences between cobots and traditional robots, it is crucial to conceptualize cobots, both in terms of identifying suitable applications and tasks, alongside expounding the health and safety ramifications in industrial environments. In practice, it is often unclear what separates cobots and old-school robots; this can raise a number of safety concerns related to safety and co-bot performance in general. This raises the question: in what ways do cobots differ from traditional robots [3].

In safety, collaborative robots are often equipped with advanced sensors and safety mechanisms capable of automatically slowing down or stopping when human proximity is detected. However, conventional industrial robots: typically work in specialized isolated areas and require safety fences or barriers to prevent contact with humans and avoid accidents.

Collaborative robots are also highly flexible and adaptable, able to be quickly reprogrammed to perform different tasks, suitable for low-volume, multi-variety production environments.

Equipped with a user-friendly interface and simple programming, operating collaborative robots usually does not require specialized programming knowledge, ordinary workers can use them after simple training.

Collaborative robots have typically lower costs, suitable for small and medium-sized enterprises (SMEs), can be quickly deployed, and pay back the investment.

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However, for traditional industrial robots, there is a higher initial investment, suitable for large enterprises and large-scale production lines.

In application scenarios, collaborative robots are suitable for scenarios that require human-robot collaboration, such as assembly, packaging, quality inspection, and the ability to work with human workers to complete complex workflows.

Traditional industrial robots are mainly used for high-intensity, high-precision repetitive tasks, such as welding, spraying, handling, etc., usually working in an environment with no human intervention.

2.3. Main characteristics of collaborative robots

Apart from safety and flexibility which have been mentioned above, cobots have some other characteristics below.

Collaborative robots are often equipped with user-friendly programming interfaces, and can even be programmed through a teach mode (manually guiding the robot through tasks), lowering the barrier to use.

Thanks to easy programming, collaborative robots can be deployed and commissioned in a short period of time, reducing downtime and increasing productivity.

Collaborative robots are often more cost-effective than traditional industrial robots and can significantly reduce the cost of automation, especially in low-volume, multi-variety production.

By collaborative robots working in tandem with human workers, productivity and product quality can be improved and scrap rates reduced.

Many collaborative robots integrate machine learning and artificial intelligence technologies that can improve efficiency and accuracy through data analysis and self-optimization.

Collaborative robots can be networked to enable remote monitoring and maintenance, identifying and solving problems in a timely manner and reducing downtime.

3. Industrial application in different fields

3.1. Automobile manufacturing

Ford has implemented cobots in its Cologne, Germany plant to assist with the assembly of Fiesta vehicles. These cobots work alongside human engineers to perform tasks such as smoothing textural inconsistencies and vacuuming

At BMW's Dingolfing plant, LBR iiwa cobots are used to assemble front axle differentials. These robots handle heavy components, reducing the physical strain on human workers and improving precision.

General Motors (GM) uses cobots to load and unload CNC machines, which helps maintain a consistent production flow and reduces downtime.

3.2. Electronics and appliances manufacturing

The manufacturing plants for appliances use cobots at Samsung for quality inspection tasks as they use robots which use advanced visual systems to detect errors for ensuring that it complies with their rigorous quality standards. Cobots are used for pick and place operations in LG Electronics, handling components and placing them accurately on assembly lines. This automation speeds up the production process and reduces the risk of human error.

In the appliance manufacturing of Panasonic, cobots are used for packaging and palletizing tasks. Cobots handle repetitive tasks efficiently, reducing the physical strain on human workers and increasing overall productivity.

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3.3. Food and beverage industry

In JAKA Robotics, cobots are used for packaging and palletizing tasks, handling payloads up to 18kg. They ensure efficient warehousing by performing these tasks with great accuracy and speed.

For inspection and sorting, the cobots of JAKA Robotics are equipped with advanced vision systems can inspect and sort food products by identifying shapes, colors, and defects. This ensures high-quality standards and reduces waste.

JAKA Cobots are qualified to precisely dispense and decorate food items, such as applying coatings or decorations, ensuring minimal wastage and high consistency.

3.4. Pharmaceutical and chemical industry

Collaborative robots also play a crucial role in both the pharmaceutical and chemical industries.

In the pharmaceutical industry, cobots are used for mixing and dispensing as well as quality control and inspection. In Robotiq, cobots are used to mix, count, dispense, and inspect medications in pharmaceutical labs. This helps optimize processes, reduce waste, and improve yield while ensuring quality control to meet strict regulatory requirements. Cobots are employed for quality control tasks by Universal Robots, such as inspecting medications and ensuring they meet stringent standards. They can handle repetitive tasks with high precision, reducing human error. In chemical industry, cobots play a vital role in handling hazardous materials and assisting with injection molding processes.

ABB uses cobots to handle hazardous chemicals, reducing the risk to human workers. They can perform tasks such as mixing, transferring, and packaging chemicals in a controlled and safe manner. Cobots also assist in injection molding processes, ensuring precise and consistent production of chemical components. This improves product quality and reduces waste.

4. Collaborative robot technology

4.1. Sensor technology

On the basis of the paper from the U.S. National Institute of Standards and Technology (NIST) which discusses the development of performance metrics for collaborative robotic systems, multiple sensor platforms are used in the development of collaborative robots. NIST uses multi-camera motion capture systems, stereo cameras, RGB-D cameras, force/torque sensors, and inertial measurement units (IMUs) to monitor and measure robots and their operating environments. Specific application of sensors can be found in collaborative robot safety and Human-Robot interaction (HRI).In collaborative safety, sensors are used to enable Speed and Separation Monitoring (SSM) to ensure that the robot is able to stop in time and maintain a safe distance when it detects the presence of a human. The Power and Force Limitation (PFL) function relies on sensors to measure and limit the pressure and force exerted by the robot on the human to prevent injury. In HRI, sensor systems are designed to identify and locate humans in flexible factory environments, including stereo sensing using multi-spectral cameras (RGB and NIR)[4].

4.2. Human-robot interaction/collaboration technology

Cooperation and collaboration are different types of interactions. Collaboration is a sequence of shared actions toward a shared goal. It requires that both collaborators are actively engaged in the task [5].

But the Human-Robot Interaction (HRC) global approach much more than that. In the context of Industry 4.0, HRC should be understood as a complex sociotechnical arrangement where agency is distributed among humans and nonhuman agents, such as machines, robots, sensors, programs, and similar devices, rather than being exclusively attributed to humans.[5]

Cobots are designed with advanced safety mechanisms such as collision detection, force control, and safety-rated sensors to ensure they can operate safely in close proximity to humans.

These robots are equipped with user-friendly interfaces and programming methods that allow even non-experts to interact with and program them easily. This includes voice commands, gesture recognition, and touchscreens.

Cobots use machine learning algorithms to adapt to their environment and improve their performance over time. This includes learning from human actions and adjusting their behavior accordingly.

Utilizing computer vision and other sensory modalities, cobots can better understand and respond to their surroundings. This helps in tasks that require precision and adaptability.

Cobots are used in various industries for tasks that require human-robot collaboration, such as assembly lines, healthcare, and logistics. They can handle repetitive tasks while humans focus on more complex activities.

The integration of cobots into the workforce raises important ethical and social questions, including the impact on employment and the need for regulations to ensure safe and fair use.

4.3. Machine learning and artificial intelligence in collaborative robotics

Artificial Intelligence (AI) and Machine Learning (ML) have changed the face of advanced robotics in recent years This brand-new research puts robotic vision, tactile sensing, and mobility in perspective with a richer understanding of AI, algorithms and hardware, and the very desktop tools utilized to expedite analysis [6].

Cobots equipped with ML algorithms can learn from their interactions with the environment and improve their performance over time. This includes tasks like object recognition, path planning, and anomaly detection.

AI enables cobots to process and interpret sensory data from cameras, LIDAR, and other sensors. This allows them to understand their surroundings, recognize objects, and make decisions based on visual and spatial information.

AI algorithms help cobots make autonomous decisions in real-time. For example, they can adjust their actions based on changes in the environment or the behavior of human coworkers.

AI and ML facilitate smoother and more intuitive interactions between humans and robots. Cobots can predict human actions and adjust their behavior to assist effectively, enhancing teamwork and productivity.

The usage of ML (Machine Learning) algorithms allows manufacturers to collect data from cobots and anticipate the need for maintenance, thereby decreasing downtimes, and extending the lives of the robots while guaranteeing they remain productive and dependable.

AI enables cobots to perform complex tasks such as assembly, welding, and quality inspection with high precision and efficiency. They can handle variations in tasks and adapt to new requirements quickly.

5. Challenges and future developments

5.1. Challenges

Collaborative robots (cobots) can function autonomously as a core option compare to conventional industrial robots, but the contingent or experimental adoption is not completed (yet been progressed) especially for Small and Medium-sized Enterprises (SMEs). There are 23 million businesses in the EU of 27 member states, more than 99 percent of them are SMEs, which is a significant proportion.

It is because SMEs often need fast response times and versatile multi-purpose assembly systems are prominent, making them an attractive market for cobot solutions. Nevertheless, The increasing demand for these technologies for Industry 4.0 is due to several reasons, but SMEs are usually unable to implement them on their own platform.SMEs find the successful implementation of Industry 4.0 technologies challenging because of the problems inherent to automating mechanical, electrical, and software engineering tasks [7].

Moreover, Ensuring the safety of human workers is paramount. Cobots must comply with stringent safety standards and regulations, such as ISO/TS 15066. This kind of standards presents safety requirements for cobots systems. Developing safety mechanisms such as Power and Force Limiting (PFL) is crucial in safety fields. For instance, PFL ensures that the force exerted by the robot is within safe limits, preventing injuries.

Effective HRI requires cobots to understand and predict human actions accurately. This involves complex algorithms for perception, decision-making, and learning. Achieving seamless and intuitive interaction remains a significant challenge.

Integrating various sensors (e.g., cameras, LIDARs, force-torque sensors) and ensuring their accurate calibration is technically challenging. These sensors must work harmoniously to provide real-time data for safe and efficient operation.

The deployment of cobots raises ethical concerns, such as job displacement and privacy issues. Addressing these concerns is essential for the broader acceptance of cobots in society. Cobots need to be scalable and adaptable to different tasks and environments. Developing flexible systems that can be easily reprogrammed and reconfigured is a technical challenge.

5.2. Future developments

Future cobots will leverage advanced AI and machine learning algorithms to improve their learning capabilities, adaptability, and decision-making processes. This will enable them to handle more complex tasks and environments. There is no denying that Cobots require more advanced algorithms in order to maximize their potential in high-mix, low-volume production. They should enable Cobots to work independently in new environments with a minimum of human intervention. Movement Planning Algorithms help Cobots position themselves accurately in known environments, while Collision Detection Algorithms enable them to respond quickly to changes in the dynamic surroundings. These algorithms are typically dependent on data gathered from cobot sensors regarding its whereabouts [8].

The development of more sophisticated sensors and perception systems will enhance cobots' ability to understand and interact with their environment. This includes improvements in computer vision, tactile sensing, and multi-modal perception. According to the experimental results of the Institute of Mechatronics System and the University of Isfahan, visual and tactile perceptions alone are not sufficient for intrinsically safe robotics as each system exhibits some lack of information, thus decreasing both productivity and protection. It is clear that perceiving in a mix of vision and tactile can provide a way to enhance both productivity and safety [9].

Research will focus on making cobots more intuitive and user-friendly, enhancing their ability to work seamlessly with humans. This includes better natural language processing, gesture recognition, and adaptive learning.

Complex programming is one key issue stopping cobots from being diffused into industrial environments. In order to solve this problem, a pyramidal parametrized approach exploiting cobot collaborative features has been presented to simplify the programming process as well maintain high flexibility.

This method is called Interactive Refinement Programming (IRP) , which allows normal users to develop production processes by progressively optimizing pre-defined standard and parameterized

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tasks. The programming methodology uses a hierarchical pyramid framework consisting of Primitive Instructions, Skills and Tasks. Skills consist of basic instructions, and Tasks are logical sequences of skills.

There are four stages in the implementation steps, which are separate setup stage, teaching stage, calibration stage and execution stage. In the setup phase, engineers convert manual operations into robot metalanguage to generate skill sequences. In the teaching phase, non-expert users are guided by the software to set the input parameters for each skill. In the calibration phase, a low-speed test and a predefined calibration package allow the user to correct errors in execution. In execution phase, after completing the teaching and correction, the robot can start executing tasks.

The economic viability of robotics investments can be evaluated through Monte Carlo simulation analysis. Payback periods can be determined by calculating batch thresholds and labor hours saved. Practical tests in one of ABB's production departments validated the feasibility of the method. Non-expert users were able to set up the robot application in a short period of time, demonstrating the flexibility and ease of use of the approach. The approach above significantly reduces the complexity of robot programming through a hierarchical pyramid framework and interactive refined programming, enabling non-expert users to effectively set up and operate collaborative robots. A detailed economic analysis demonstrates that collaborative robot investment is economically viable in low-volume and highly customized production environments, resulting in significant labor cost savings. Tests in real industrial environments show that the approach is not only theoretically feasible, but also effectively implemented in practice, with high practical value [10].

6. Conclusion

In this study the current status and application areas of industrial robots have been thoroughly evaluated. The research examined specific cobot applications and examples in various industries like automotive, electronics and appliances, food and beverage and pharmaceutical and chemical industry. The significant advantages of cobots such as improved working efficiency and productivity, reduced operational costs and optimized working environment. It has already been proved that collaborative robot is an integral part in modern industry because of its high adaptability, safety and efficiency.

This research observes the massive benefits of cobots for revolutionizing and modernizing industrial processes as we know them. By applying other innovative technologies like sensors, human-robot interaction (HRI), machine learning, and artificial intelligence, cobots are qualified to execute tasks with high precision and reliability. This not only maximizes production, but also maintains highly safe standards and quality control. The results highlight the significance of continuous investment in collaborative technology to maintain competitive power and drive innovation in the industry.

Looking ahead, future research should focus on overcoming the current challenges faced by cobots, such as technical bottlenecks, regulatory issues, and market acceptance. Like the introduction of IRP technology above which allows the average user to develop a production process by stepwise optimization of predefined criteria and parameterized tasks. Thus, solving the problem of complex programming as well as enhancing the ability of cobots to work seamlessly with humans and saving labor costs.

Collaborative applications are more complex than traditional industrial robot applications because they typically involve the interaction of two different kinds of resources (usually a human being and a robot) and hence offer advantages and disadvantages. Human factors and cobot capabilities must also be integrated with all the features of modern production systems in Industry 4.0 to ensure the workcell can attain its full potential. With humans bringing their cognitive abilities to AI and machine learning, which will further improve cobots ability in handling more complex and dynamic tasks. In addition, the development of more intuitive, user-friendly interfaces that are easier to be adopted by different industries will also play a critical role. Continued exploration into the ethical and social implications of cobot application will also be crucial to make sure they can be integrated into the workforce. To find new developments for collaborative robots in the future, human interaction and learning technologies should be related with the knowledge of psychology and behavioral sciences from other branches. This interdisciplinary approach is crucial for the successful application of cobots. By addressing these issues, future research can pave the way for even more sophisticated and versatile cobots, which will ultimately contribute to the advancement of highly intelligent industry and the broader industrial landscape.

References

[1] *Silva, M. D., Regnier, R., Makarov, M., Avrin, G., & Dumur, D. (2023). Evaluation of intelligent collaborative robots: A review. 2023 IEEE/SICE International Symposium on System Integration (SII), 1-7.*

[2] *Guertler, M., Tomidei, L., Sick, N., Carmichael, M., Paul, G., Wambsganss, A., ... Hussain, S. (2023). WHEN IS A ROBOT A COBOT? MOVING BEYOND MANUFACTURING AND ARM-BASED COBOT MANIPULATORS. Proceedings of the Design Society, 3, 3889–3898.*

[3] *Vicentini, F. (2020). Collaborative robotics: A survey. Journal of Mechanical Design, 143(4), 040802.*

[4] *Marvel, J. A. (2017). Sensors for safe, collaborative robots in smart manufacturing. 2017 IEEE SENSORS,1-3.*

[5] *Weiss, A., Wortmeier, A.-K., & Kubicek, B. (2021). Cobots in Industry 4.0: A roadmap for future practice studies on human–robot collaboration. IEEE Transactions on Human-Machine Systems, 51(4), 335-345.*

[6] *Soori, M., Arezoo, B., & Dastres, R. (2023). Artificial intelligence, machine learning and deep learning in advanced robotics: A review. Cognitive Robotics, 3, 54-70.*

[7] *Schnell, M., & Holm, M. (2022). Challenges for manufacturing SMEs in the introduction of collaborative robots. Advances in Transdisciplinary Engineering, 21, 173-183.*

[8] *Borboni, A., Reddy, K. V. V., Elamvazuthi, I., AL-Quraishi, M. S., Natarajan, E., & Azhar Ali, S. S. (2023). The Expanding Role of Artificial Intelligence in Collaborative Robots for Industrial Applications: A Systematic Review of Recent Works. Machines, 11(1), 111.*

[9] *Mohammadi Amin, F., Rezayati, M., van de Venn, H. W., & Karimpour, H. (2020). A Mixed-Perception Approach for Safe Human–Robot Collaboration in Industrial Automation. Sensors, 20(21), 6347.*

[10] *Giberti, H., Abbattista, T., Carnevale, M., Giagu, L., & Cristini, F. (2022). A Methodology for Flexible Implementation of Collaborative Robots in Smart Manufacturing Systems. Robotics, 11(1), 9.*