ISSN: 2278-4632
Vol-12 Issue-10 No.02 October 2022

Human-Robot Collaboration in Flexible Manufacturing Cells: Safety, Efficiency, and Interaction Design

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Abstract

A significant characteristic of smart manufacturing settings is the effective deployment of Human–Robot Collaboration (HRC), which has become an important component. In the manufacturing industry, there is an urgent need for human resource and corporate governance (HRC) in order to meet key industrial objectives such as flexibility, efficiency, cooperation, consistency, and sustainability. With regard to the major technologies that are now being used in smart manufacturing with HRC systems, this article presents both a comprehensive assessment and an in-depth explanation of those technologies. The work that is described here is centered on the design of human-robot interaction (HRI) systems, with a specific emphasis on the several degrees of HRI that have been seen in the industry. In addition, the study investigates the most important technologies that are now being used in smart manufacturing, such as Artificial Intelligence (AI), Collaborative Robots (Cobots), Augmented Reality (AR), and Digital Twin (DT), and addresses the uses of these technologies in Human Resource Control (HRC) systems. In this presentation, the advantages and operational examples of implementing these technologies are highlighted, with a particular focus on the significant opportunities for expansion and enhancement in industries such as the food and automotive industries. Nevertheless, the study also discusses the constraints that are associated with the use and implementation of HRC, and it offers some insights into the manner in which the design of these systems need to be tackled in regards to future work and research. All things considered, this article offers fresh perspectives on the present status of human resource control (HRC) in smart manufacturing and functions as a valuable resource for those who are interested in the continued development of HRC systems within the sector.

1. Introduction

The field of smart manufacturing places a significant emphasis on human–robot cooperation (HRC), which is a crucial area of attention. There is a substantial need for human resource control systems in a number of different industries, including the food and automotive industries. In the past, robots have been employed in the industrial industry to carry out jobs that are inherently repetitive and straightforward. However, as a result of developments in technology, academics are now investigating methods to combine human experience, decision-making, and critical thinking with the power, repeatability, and precision of robots in order to carry out complicated tasks.

It is anticipated that robots will collaborate with people in the manufacturing industry to reach greater levels of efficiency, quality, and flexibility. This is becoming more common as automation technologies are increasingly used. The HRC has emerged as a potentially fruitful strategy for accomplishing these objectives. Through cooperative efforts, people and robots are able to combine their own capabilities and talents in order to improve the efficiency of production processes. As a result, the usage of human-robot cooperation (HRC) in manufacturing is causing a shift in the conventional approach to the utilization of robots. As a result, researchers are increasingly concentrating their efforts on discovering new methods to use human–robot collaboration in order to improve the efficiency and quality of production. It is [1].

Recent research has shed light on the advantages that may be gained from human and robot cooperation in the field of smart manufacturing. Productivity is one of the most important advantages that may be gained. It is possible for manufacturers to attain better production rates and quicker cycle times by using the capabilities of both people and robots. It is [2]. In recent times, there has been a rise in the demand for personalized items, which has directly led to a growth in the production of customized goods in order to satisfy this need. Because of this, manufacturers are making adjustments to their working environments in order to make them more intelligent and dependable. It is because of this that human–robot collaboration systems have been developed in the field of smart manufacturing. These systems allow people and robots to work together in a harmonic manner in order to reach higher levels of productivity and quicker cycle times, all while maintaining a safe and effective working environment. Through the use of their various skills, robots are able to take on activities that are either boring or harmful, while humans are able to handle tasks that are more sophisticated and experimental. The capabilities of these systems have been further improved by the development of advanced technologies like as machine learning and artificial intelligence. These technologies have made it possible for robots to educate themselves from people and adapt to changing conditions. The incorporation of human–robot cooperation systems has brought about a revolution in the industry, providing manufacturers with a means to increase workplace safety, productivity, and efficiency among their employees [3].

Within the context of smart manufacturing, the following study offers a comprehensive analysis of the present level of research in human–robot cooperation. In particular, it makes an effort to describe and categorize human–robot interactions in terms of work tasks, direct contact, and simultaneous and sequential processes. Additionally, it strives to define and categorize human–robot cooperation in terms of collaboration levels, work roles, safety control modes, and communication interfaces. In the next section, it examines the most recent technical advancements in the implementation of HRC systems and provides examples of various industrial applications. The most important difficulties that HRC faces are emphasized and utilized to determine the future courses of study.

2. Human–Robot Interaction Classification

For businesses that are competing to enhance their production efficiency, industrial robots have emerged as an essential component. According to projections made by the International Federation of Robotics, the global robot manufacturing sector is expected to see a growth rate of 13% in January 2019 [5]. In addition, a great number of businesses are concentrating their efforts on the incorporation of unique characteristics into the robotic systems that they are contemplating purchasing themselves. Among these unique characteristics may be the need for robots that are improved in terms of their user-friendliness, flexibility, and safety. There is a rising desire for robots that are able to operate alongside people without presenting a danger to their safety, while also being able to adapt to a broad variety of jobs and situations [6]. This demand is a direct outcome of the fact that. Businesses of all sizes are discovering that it is becoming more practical to include robotic systems into their production processes. This is due to the fact that collaborative robots, often known as "cobots," continue to gain popularity. As a consequence of this, industrial settings may result in increased levels of both efficiency and adaptability. When it comes to this procedure, the

ISSN: 2278-4632
Vol-12 Issue-10 No.02 October 2022

incorporation of human–robot interaction phases is of utmost importance since it enables the human operator and the robot to work together in a more smooth manner. In the manufacturing process, for example, cobots may be programmed to carry out activities that are physically difficult or repetitive. This allows human operators to devote their attention to more complicated and creative parts of the system. The effective integration of cobots has the potential to ultimately result in an industrial environment that is safer, more productive, and more adaptive [7]. Both the precise activity that has to be completed, the shared workspace, the degree of direct contact between the person and the robot, as well as the sequencing and timing of the numerous processes that are involved, all have a significant role in determining the nature of the interaction that occurs between humans and robots. The following are the four basic sorts of interactions that may be roughly classified as occurring between people and robots [8,9]:

A situation in which a human operator and a robot are engaged on distinct tasks in different workspaces without the need for physical boundaries is referred to as a coexistence interaction [10,11]. This interaction is a kind of interaction. Robots, for instance, may be in charge of heavy lifting and assembly, while human operators would be in charge of quality control and supervision. This sort of contact offers for better flexibility and efficiency in the manufacturing process [10], since it only involves a minimal link between the person and the robot.

This sort of interaction between humans and robots includes a situation in which a human operator and a robot share the same workspace, but operate at separate times in a sequential fashion. This type of interaction describes a scenario in which the human and the robot work together. It is the responsibility of both the human and the robot to carry out certain duties, and they interact with one another by giving each other messages and offering feedback. In order for the human and the robot to successfully engage in this kind of interaction, a high level of coordination and synchronization is required! The human operator and the robot are both focusing their attention on the same objective and working in a sequential manner in order to accomplish the desired result in this scenario. While the robot is carrying out the actual manufacturing process, the human operator could be tasked with the responsibility of loading a machine with raw materials. To guarantee that the machine is loaded appropriately and that the production process is carried out without interruption, the human operator and the robot would need to collaborate in accordance with one another [8].

Interaction based on cooperation: The term "cooperation relation" describes a situation in which a human operator and a robot work together towards a same goal, but who have different interests in the process. A direct link does not exist between them, despite the fact that they both have access to the same technology tools in order to get information on the job assignment. The human operator and the robot do not come into conflict with one another's work, despite the fact that their workspaces may overlap. The primary emphasis is on accomplishing a shared objective while simultaneously following individual interests. In a warehouse, for instance, a human operator may be in charge of monitoring inventory and fulfilling orders, while a robot would be in charge of material handling and transportation for the facility. In order to accomplish their respective goals, the human operator and the robot are both able to access the same information on the status of orders and inventory, but they do it separately. When humans and robots engage in this manner, it helps to ensure that resources are distributed effectively and that they are coordinated.

Collaboration interaction is a situation in which a human operator and a robot in the same workplace at the same time work together to achieve a shared objective. This scenario is referred to as a collaboration interaction. The human operator and the robot are required to have a high degree of coordination and communication in order to engage in this sort of contact, which is not as sophisticated as cooperative interaction [12]. Through the use of modern sensing technologies, the human operator and the robot work closely together in cooperative interaction. This allows for direct contact between the two of them, which can be controlled by the human operator. The action of one person has an instantaneous impact on the other. Considering that the human operator and a robot might work together to assemble a complex component, the human operator might be responsible for the more delicate aspects of the task, such as placing, aligning components and making decisions [13], while the robot might be responsible for heavy lifting and precise positioning. If the human operator and the robot are able to work together in a way that is both fluid and efficient, then the cooperation interaction will be successful. There are two types of connections that might exist between a person and an operator: a physical connection and a contactless connection. In order to fulfill the criteria of the connection type in this kind of interaction, various information may be considered necessary. In order for the robot to be able to comprehend the person's intentions and respond appropriately, it is possible to establish physical links between the human and the robot via the measurement of forces and torques [14]. Furthermore, in order to facilitate the working relationship between the human and the robot, a contactless link is established between the human and the robot. This is accomplished by using the necessary communication mechanisms. Using advanced sensing technologies such as machine vision and haptic feedback, it is possible to detect and analyze both direct (speech, gestures, force) and indirect (intention recognition, eye blinking) communications between the human and the robot. This will allow the robot to comprehend the human's intentions and respond appropriately and appropriately to the requirements of the task [15].

3. HRC in Smart Manufacturing: Industrial Cases

Due to the fact that some stores generate as many as 10,000 meals on a daily basis, the food business plays an important part in the economy of Europe [48]. There are three primary processes that make up the manufacturing cycle: cultivation, production, and reaching the point when the finished product is ready to be sold on the market. The leaders of the food industry are concentrating their efforts on altering the business strategy so that it is based on demand. This was of utmost significance during the early phases of the COVID-19 pandemic, which had a detrimental effect on the robustness of the supply chain [49]. For this reason, the advent of digitalization and the technical contributions of Industry 4.0 are greatly necessary to drive the transformation of food production in order to improve the sector's potential to remain sustainable [50].

The use of robotics in agriculture brings about improvements in the collecting of data on the development of plants, soil, and crops. Because sensors are designed to offer real-time data on the expiration date of the items, the deployment of sensors is boosting the system's dependability via intelligent packaging [51]. This is because sensors are developed to deliver this information. For the purpose of fruit harvesting, a robot that is linked to a gripper camera is employed to carry out the picking and inspection activities [52]. Improvements in quality control assurance are possible with the incorporation of an image processing system into the camera equipment. Additionally, the installation of a vision system on the cobot will increase the consumer's trust that the food is safe and clean. This is because the camera will be able to identify extraneous things, such as glasses or plastic, that may be present in the meal. There are several operations that take place in catering facilities, such as cooking and baking, and the production challenge is located at the end of the line, as stated in [48]. Food is processed in this region by manual procedures, which are light and may be completed by people; nevertheless, they demand a high degree of repeated skill, which the human worker does not possess at this moment in time.

ISSN: 2278-4632
Vol-12 Issue-10 No.02 October 2022

Maintaining a state of constant innovation and improvement is essential for the food manufacturing industry. It is possible that difficulties may occur as a result of the implementation of technologies associated with Industry 4.0 and the trusting of industrial robots to accomplish jobs in conjunction with a human operator. However, if these systems are not implemented in a timely manner, the chance to reap the benefits of these technical advancements will be delayed. As a result, the industrial sector will not see any discernible and concrete changes. Considering that some operations cannot be automated and need human skill, such as supplying machines with components to maintain the work continuous, the implementation of HRC systems will progressively guarantee that production processes are functioning in an optimum manner.

3.1. Automotive Industry

One of the most important industrial sectors in the world is the automobile industry. In the United Kingdom alone, the automobile industry is responsible for the employment of over 3.7 million people, and its contribution to the GDP of the United Kingdom is approximately $26 billion [49]. Eighty-three percent of manufacturing units in the automobile sector entail assembly duties [22], which indicates that assembly cells are playing a significant role in the industry. With that being said, there are some manual processes that still need more flexibility and resilience in order to be carried out effectively. As a result, depending only on the industrial robot to carry out certain jobs may not be a feasible option since human capabilities cannot be completely substituted [53]. As a result, the primary objective is to integrate the capabilities of both people and robots in order to work together, while keeping safety in mind in order to avoid any accidents that may occur while the task is being done [29].

As of [9], the collaborative robot is in charge of the screwing job during the assembly stage. This is accomplished by sensory integration with a human operator who will be able to share the work space and the task. Through the installation of the vision system, the collaborative robot is also able to gather information about the working environment and the intents of humans. This information will be used for additional advancements, such as the planning of paths and the creation of forecasts about human movement. As a consequence of this, the installation of the HRC system is displaying the requisite ability to carry out activities that are difficult.

4. Key Findings and Future Research Directions

For enterprises to maintain their competitive edge in the age of Industry 4.0, it is essential to improve industrial productivity, efficiency, and cost savings via the use of technologies such as artificial intelligence, robots, and the internet of things [54]. To effectively navigate the voyage of digital transformation, however, it is necessary to do more than just install new technology. It is necessary for there to be a significant mental change across the whole of the business, beginning with a strong commitment from the leadership and a distinct vision for the future [55]. The potential of digital technologies must be understood by leaders, and they must be able to successfully convey the advantages of these technologies to the business. The promotion of a culture that values innovation, adaptability, and ongoing education is very necessary in order to provide support for digital transformation. The promotion of experimentation, the recognition of risk-taking, and the establishment of an atmosphere in which workers feel empowered to adopt new technology are all necessary steps in this process. The engagement of workers at an early stage in the process of change, the collection of their input, and the resolving of their issues are some crucial aspects. Employees need to be equipped with the skills essential to operate alongside new technology, and this may be accomplished via the implementation of comprehensive training programs and upgrading

 ISSN: 2278-4632
Vol-12 Issue-10 No.02 October 2022

activities. Companies are able to demonstrate the value and advantages of digital transformation by beginning with pilot projects, which enable them to test new technologies in a controlled setting before scaling up their operations [56]. Collaboration with technology providers, research institutes, and peers in the sector makes it easier for members of the industry to share their expertise and ensures that businesses remain current with the most recent trends and best practices. To achieve success, it is essential to implement change management methods that are effective. These practices include the development of a clear plan, the communication of the goal and advantages of the transformation, and the establishment of communication channels that are both frequent and transparent. The need of putting an emphasis on data-driven decision-making, investing in capabilities for data analytics, and regularly reviewing and enhancing digital projects are all components that should be taken into consideration. By tackling these difficulties, businesses and industries will be able to effectively traverse the road of digital transformation and capitalize on the advantages of human resource control systems in smart manufacturing within the context of the fourth industrial revolution.

The incorporation of artificial intelligence, cobots, augmented reality, deep learning, and human-computer interaction into smart manufacturing helps to enhance data processing, control operations, and production efficiency. The digitalization of data is made simpler by these approaches, which allows for better management, analysis, and use of the data. Real-time data insights are provided by intelligent systems, which in turn leads to made choices that are more informed, decreased waste, cost savings, and higher productivity. In addition, smart manufacturing combines several business divisions, such as production, customer service, and supply chain management, which results in improved cooperation and management of data. The manufacturing of high-quality goods, improved product traceability, and increased customer satisfaction are all outcomes that are a direct result of this [57].

When it comes to manufacturing, the implementation of human-robot cooperation (HRC) presents a viable alternative to standard automation methods. This helps to reduce complexity and enables people and robots to work together more effectively. Interfaces that are easy to use paves the way for interactions that are intuitive [58]. The future of manufacturing may be shaped by HRC systems. These systems have the potential to improve production processes in terms of efficiency, productivity, and flexibility [22].

Nevertheless, the intricacy of collaborative robot technology restricts its present use to straightforward manufacturing procedures, which has a negative impact on the confidence of operators and their ability to make decisions in high-pressure circumstances. In addition to ensuring that safety and accessibility are maintained, it is essential to design and perceive the roles that humans and robots play [59]. It is necessary to have a comprehensive grasp of the administration of such complex and sophisticated working systems in order to construct an integrated human-robot collaboration (HRC) system. This system will consist of collaborative robots, human operators, sub-systems, such as vision or sensing systems, and machine learning or deep learning methodologies. However, some operators may lack the essential knowledge or competence to efficiently manage these integrated technologies. The operation of these systems requires specific abilities, and some operators may lack these qualifications. Operators who are not acquainted with these technologies may have difficulties as a result of the complexity involved, which makes training time-consuming and necessitates considerable expenditures in education and the development of skills [56]. In addition, for businesses that have a high staff turnover rate, the provision of consistent and all-encompassing training programs becomes a bottleneck in the process of ensuring that new workers are able to adjust to these changes. This may be expensive and requires continual efforts to ensure that operators are kept up to speed with the latest technological developments. In addition, it is of the utmost importance to note that the use of AI strategies in smart manufacturing settings creates ethical and legal difficulties. There are a number of important factors to take into account, including the protection of data privacy and security, the elimination of algorithmic biases, and the observance of legislation concerning safety and occupational rights [60]. In order to successfully negotiate these issues and guarantee that the adoption of technology is in accordance with ethical principles and regulatory frameworks, manufacturers are need to [54].

5. Conclusion

The Human–Robot Interaction (HRI) idea has been the primary emphasis of this enlarged version of our work. Additionally, we have presented the Human–Robot Collaboration (HRC) concept as a whole functioning system, including its definition, categorization, and characterisation. Throughout this discussion, we have stressed how important it is to design the structural components of the HRC system. In addition, our article has investigated the integration of human resource control (HRC) with smart manufacturing, which includes the use of technologies such as artificial intelligence (AI), collaborative robots (Cobots), augmented reality (AR), and digital twins (DT) that have developed in the age of Industry 4.0. Our demonstration of how collaborative robots, which are equipped with cognitive sensing and vision systems, are used to improve efficiency in the food and automotive industries was accomplished by using examples from both industries. In these sectors, the successful application of collaborative robot systems demonstrates the relevance of human-robot collaboration (HRC) in the industrial methods that are now in place. Through the use of human operators' knowledge and skill in conjunction with the capabilities of robots, collaborative robots offer a great deal of potential for maximizing the efficiency of production processes. Nevertheless, it is of the utmost need to overcome the present issues that are linked with HRC. These challenges include interface, safety, compatibility, and complexity. A substantial amount of research is necessary in order to build solutions that are both stable and intuitive, and that can be applied to a variety of industrial areas [61].

The manufacturing business has the potential to undergo a transformation as a result of the cooperation between human operators and robots, which will enable production systems that are more flexible, efficient, and effective. For example, including in-process quality control into HRC systems is a promising research topic since it has the potential to enhance production processes while still maintaining stringent product quality requirements. It is possible for us to expand the knowledge of human resource control (HRC) systems in industrial settings and their application by following these study paths. This will allow us to drive innovation and improve operational efficiency across a variety of manufacturing industries. Ensuring the safety levels of human-robot collaboration (HRC) systems and carefully designing the roles of humans and collaborative robots will be essential for their successful adaptation in manufacturing environments. This will allow for consistent production even in the presence of technical issues or sudden changes in the working environment.

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