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Collaborative Robots: Human-Robots Coexistence in Industrial Environments

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Review Article

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Abstract

The fourth industrial revolution, with the emergence of artificial intelligence and robotics, is transforming various industries, including the manufacturing industry. Robots are increasingly replacing repetitive and dangerous tasks and helping humans to do more complex and creative tasks. Meanwhile, a new generation of robots called collaborative robots are emerging that can work alongside humans in industrial environments. In industrial environments, the coexistence of humans and robots brings many challenges that require appropriate and efficient solutions. One of the most important challenges in this field is to create coordination and cooperation between humans and robots. Humans and robots are two beings with different structures and capabilities that require effort and the intersection of their abilities to achieve greater productivity and efficiency. In addition, the issue of human security and protection in the presence of robots is also one of the important challenges that should be given special attention. In general, the coexistence of humans and robots in industrial environments requires careful planning, proper training, and the use of advanced technologies to solve problems and improve performance.

Keywords: Human-Robot Interaction; Human-Automation Interaction; Industrial Human-Robot Coexistence

Abbreviations

HCA: Human-Centered Assembly; IOT: Internet of Things; HCPS: Human-Cyber-Physical System; AR: Augmented Reality.

Introduction

The history of robotics goes back to the early days of industrialization, when simple automation machines were developed to perform routine and repetitive tasks. In the following decades, further advances in control engineering and computing enabled the development of more complex robots capable of performing a wider range of tasks [1]. But as an integral part of the industrial revolution, 4.0, intelligent manufacturing robots represent a significant leap in the field of industrial automation [2]. Today, intelligent robotics has the potential to revolutionize various industries by enhancing output, simplifying operations, and enriching interactions with other industry components. In this regard, the best way to analyze emerging technologies and trends in intelligent robotics is to address key research questions, identify challenges and opportunities, and propose best practices for responsible and beneficial integration in different sectors [1] to facilitate the use of these technologies in the industry.

Industrial robots are mainly designed to perform a wide range of tasks in industrial environments and revolutionize production and automation processes. They are known for their accuracy, power and reliability [3]. Collaborative robots are robots specifically designed to collaborate with humans in a collaborative work environment. These robots use advanced sensors and software to understand their surroundings and safely interact with humans. Collaborative robots can perform a wide range of tasks, including: assembly, transportation, inspection, assistance to workers. So far, the strongest feature of these robots has been their ability to work independently but in a predefined smart factory environment, where they communicate with other systems by using IoT technologies [4,5]. On the other hand, the interest in joint cooperation between robots and humans also has problems ahead, human fatigue is a problem for humans-robots. Continuous intellectual and manual work leads to the accumulation of fatigue, which reduces the efficiency of manual work [6]. This can severely affect work processes in cases where joint work is being done between humans and robots [7]. Hence the importance of focusing on human-robot collaboration, ethical considerations, sustainable practices, and addressing industry-specific challenges to take full advantage of the opportunities offered by intelligent robotics [1]. Especially where the joint cooperation of these two is going to open a new door to transformation and creating synergy in the world of industrial work.

Literature Review and Background

Development of dimensions of coexistence and greater integration with the human mind Industrial or collaborative robots are usually used for tasks such as welding, assembly, material handling and quality control in industrial environments. Industrial robots are widely used in manufacturing industries. They play a central role in increasing production efficiency, reducing production costs and ensuring product quality [1]. Controlling an industrial robot using human brain waves as a means of communication is a new method to translate human brain activities into a set of commands to control the robot [8]. Brainwave-controlled robotics is considered a key element in human-centered assembly [9]. For this reason, in many cases, operators work in parallel with robots in the execution of the flow [10].

Using brain waves to communicate with the robot has two major advantages:

- It allows an operator to control a robot while performing a robot-related task, which will have a positive effect on the productivity of robotic tools.
- It provides an auxiliary channel for multi-modal cooperation with the robot. For example, using mental commands to control a robot can overcome the problems often associated with using voice commands in a noisy robotic environment [8].

However, robust and accurate extraction and interpretation of brain signals in brain robotics is critical for reliable task-oriented and opportunistic applications such as brainwave-controlled robotic interactions [11]. Promoting the use of collaborative robots (Cobots) in industrial environments [12], enables humans and robots to exchange information and share their tasks, which leads to increased efficiency, productivity and flexibility in production [13].

A Digital Twin, A Perfect But Smarter Copy of Humanoid Function

Today, in cooperative assembly or collaborative robots, by modeling the real performance of a human, a digital twin has been created to accurately imitate the joint settings of humans and robots [10]. This type of human-centered assembly (HCA) in the framework of Industry 5.0 is facilitated by four items.

- increasing the human capabilities of augmented robots,
- cognitive systems, augmented reality
- Common Intelligence
- also robotic brain-based assistance

In fact, a twin system takes control of the robot's performance by performing actions through real-time status monitoring and detailed planning. In this approach, an augmented reality-based interaction method, like HoloLens, also facilitates human-centered assembly [10].

The Explosion of Technological Development and the Shift Towards Independence

There are several technologies that play an important role in the development and performance of robots and enable them to perform their tasks with increased efficiency, accuracy and adaptability. A combination of advanced technologies from sensors and the Internet of Things (IOT) that equip them with more advanced capabilities. Sensor technology enables robots to understand and interact with their surroundings [1]. Their main features include: advanced sensor integration, adaptive learning capabilities, and data-driven decision, making capabilities [4,5]. Machine learning has revolutionized robotics beyond the limitations of conventional automation by integrating artificial intelligence and machine learning that enables robots to autonomously interact with their environment and perform more complex tasks [1]. The evolution from 1.0 Robotics to 4.0 Robotics in collaborative robots represents the advancement of robotics, with 4.0 Robotics integrating disruptive technologies such as the Internet of Robots, Cloud-on-Brain, and artificial intelligence of objects [13].

AI and ML algorithms enable robots to rapidly analyze large volumes of data (Big Data), learn from their experiences, and adapt their operations accordingly [1]. Certainly, in the era of intelligent production, it is important for manufacturing companies to use digital technologies to analyze and solve their problems and develop their business based on automatic decisions of artificial intelligence and robotics [14]. These technologies are very important to achieve the required level of automation in robots. And this automation and adaptability is very necessary to meet the evolving needs in the industry and increase productivity in different sectors of the industry, and its goal is to develop robots with more advanced cognitive abilities and integrated human-machine cooperation [1]. On the one hand, the COVID-19 pandemic has shown industries around the world that current production systems are not as flexible as expected. Labor force is the most agile and flexible source of production and at the same time the most fragile source of production because it is human. With the greater flexibility of human operators through the combination with robots, companies can make their production systems more flexible and resistant [15]. On the other hand, autonomous cognition [16], intelligent decision making [17], intelligent task control [18] and human-machine cooperation technologies [19] and intelligent manufacturing create many uncertain and complex problems that cannot be solved only by human intelligence or machine intelligence. Augmented intelligence with a combination of human-machine intelligence is a feature of new generation artificial intelligence [19]. Which along with intelligent modeling based on big data can help to solve these problems [20]?

Redefining and Separating the Dimensions of Human-robot Cooperation

The increase in the use of robotic technology has caused excitement and concern in society. As robotics continues to advance and integrate into various sectors, it is important to examine the potential risks and benefits associated with its widespread adoption [1]. The social aspects of robotics require a complete understanding of employees, work dynamics, cooperation, managerial roles, well-being and career advancement in a new way [21]. The integration of physical robots alongside human labor can increase productivity and efficiency, while intelligent robots expand cost-effective operations and enable automation through new technologies [22]. Proposed frameworks for performance Intelligent robots give them flexibility and a predetermined amount of freedom, however, complete autonomy is impossible for robots, as final approval of contractual frameworks depends on humans. The integration of robotics and artificial intelligence will involve complex questions about laws, security, ethics, and governance [23]. Today, in the manufacturing industry, the focus should be on strengthening the integration of human skills with automated machines, strengthening human-robot collaboration, and using cloud computing, the Internet of Things, big data analysis, and artificial intelligence for “smart manufacturing” [1]. Also, the “smart manufacturing” system is a hybrid intelligent system that includes humans, cyber systems and physical systems with the aim of achieving specific production goals at an optimized level. This type of intelligent system is called human-cyber-physical system (HCPS) [24].

The “intelligent manufacturing” system can be described as the integration of information, technology and human ingenuity to create a rapid revolution in the development and application of manufacturing intelligence [25]. In this definition, human ingenuity, whether directly or indirectly, is at the heart to create new solutions that are adapted to face business challenges, problems or opportunities [15]. Advances in “self-healing” machine tools [26] as well as in human-machine “mutual learning” systems [27] show that both issues are essential for the flexibility of human-machine systems, to especially for human-machine mutual learning systems that should allow human operators and (intelligent) machines to learn from each other [15] to coordinate better with each other.

Meanwhile, different dimensions of joint cooperation can be imagined:

- **Reinforced robot:** Humans have weaker muscle strength and instability over time due to fatigue compared to robots. However, poor muscle strength can be enhanced by an augmented robot such as an exoskeleton with active or passive stimulation [28].
- **Cognitive system:** Humans generally have a high-level cognitive ability that is quickly activated when needed. However, this ability is often limited by boundary conditions (eg, time constraints) and inhibited by a lack of timely information. To enhance this ability, an additional cognitive system can be developed to advise the human operator to make optimal decisions [29].
- **Mixed reality:** Humans currently only rely on direct senses to understand the environment, this inability can be enhanced with mixed reality such as augmented reality (AR) and digital twin [30].

Ultimately, redefining human-robot collaboration requires advances in quantitative validation, complex cognitive processing, physical robot limitations, measurement methods, and comprehensive performance metrics [31].

From Industry 5.0 to Operator 5.0

Industry 5.0 is rooted in the concept of Industry 4.0 and its purpose is to re-establish and expand the purpose of digital and smart technologies, beyond the profit-oriented production of goods and services and change the focus to create real prosperity, which should also include social and environmental achievements [15]. But the main point of discussion is that 5.0 Industry is not just a continuation of 4.0 Industry, and the human-centered perspective in intelligent production is very important in it [29]. Industry 5.0 is the power of the industry to achieve social goals beyond jobs and to create growth to become a flexible supplier and to place the welfare of the industry worker at the center of the production process [32]. The development of the flexible operator 5.0 concept has two aspects, on the one hand, on creating "self-resilience" for the workforce due to its natural (human) fragility, and on the other hand, on "system resilience" for all human and machine systems. The production system is emphasized to ensure that the overall system performance is optimized [15]. Although resilience is related to biological, physical, cognitive and psychological occupational health and safety as well as the productivity of each operator, But the flexibility of the system deals with alternative ways in which human-robot systems can continue to work and is a kind of shared control and cooperation between human and machine in order to ensure the operational continuity of the system [33].

It is very difficult to implement and integrate such complex socio-technical systems, therefore, the investigation of human factors and ergonomics in the industry continues by investigating different physical, cognitive and organizational dimensions. Physical ergonomics focuses on physical elements and activities. Cognitive ergonomics focuses on mental processes and human perception. Organizational ergonomics focuses on optimizing organizational aspects surrounding the system in which human work [34]. All of which are very important in integrating emerging technologies and coexisting with them in the work environment.

Challenges

Although brain robotics, especially BCI-controlled robotics, has shown significant progress in the past two decades, there are still a series of challenges in many aspects such as electrodes and chips, complex signal processing, development of neural decoders, algorithms, etc [11]. As goal of systems developed in robotic assembly is parallel interaction and real-time synchronization between physical and virtual twins for robot control and assembly execution, however, this is somewhat impractical due to communication delay and existing limitations [10].

On the other hand, during the use of a robotic system based on mental communication with a human user, the assessment of human mental workload is very important to evaluate human fatigue and well-being, because it depends on collecting high-quality signals from the human mind to transfer to the robot. It also has a negative effect [11]. Despite the significant impact and potential benefits of using artificial intelligence in the robotics sector, there are other potential challenges such as high costs, job displacement, and socio-economic inequalities [1]. Also, one of the main challenges of using service robots in the real world is that they sometimes struggle in unknown environments [35]. This indicates the need for open-ended learning techniques and improved learning algorithms. At the same time, it seems that human factor experts should be more involved in human-robot interaction research to address safety and acceptability issues [36].

Risks associated with the increased use of robotic technology include job displacement due to the potential replacement of human tasks, as well as dependence on the users or companies that develop the technology, which may lead to error or disturb if not adequately trained or adapted [37]. Despite the countless advantages that intelligent manufacturing robots or collaborative robots have, they also face certain limitations. One of the main challenges is the high initial cost of installation and integration into existing technology and production systems. In addition, there is a need for skilled personnel to manage and maintain these advanced robotic systems [1]. It seems that so far only human operators have been able to engage in creative response capacity [38] or find solutions to specific problems. Therefore, in this case, human operators have the highest share. The flexibility of the system due to agility and flexibility, as well as human ingenuity seems to be still necessary for human-robot system adaptation [15]. We also know that safety is of great importance in any brain-robot system, and such a system often requires human/brain-robot interaction. However, safety concerns pose a major challenge to the adoption of brain robotics in a wide range of applications [11]. Physically, the safety of industrial robots has been based on the safety of machines according to the ISO 12100 standard and on the principle of separation, which states that a robot should be separated from the human workspace with a fence that surrounds its range of motion. Therefore, a new model is needed to ensure safety for the use of robots in fields where there is coexistence with humans in the work environment (including intelligent self-driving vehicles and collaborative robots) [14].

In general, it can be said that smart technology (powerful technologies) present three major groups of challenges:

Challenge in Production Technology

How to continue innovation in different aspects of this technology such as design, process, materials and industrial form [39,40].

Challenges of Intelligent Technology (Enabling Technology)

Including how to achieve sustainable improvements, stability and security, and how to progress from weak artificial intelligence to strong artificial intelligence [20,41].

Coexistence of Humans and Machines

Deep integration of humans and intelligent machines [24].

Also, intelligent production based on HCPS requires humans to take on a greater role to form human-machine coexistence [42-44] which will bring various challenges, including:

- How can division of labor and effective cooperation between humans and intelligent machines be better achieved? How can the individual benefits of human intelligence and machine intelligence be fully utilized and inspired by each other to grow simultaneously? [41,19,20].
- How to enhance human-machine hybrid intelligence? [19,45].
- How can safety, privacy, ethics, and other issues that may be challenged by artificial intelligence continue to be intelligent manufacturing [41,46].

Analysis Results

The coexistence of man and machine will inevitably lead to joint cooperation between them, and this cooperation is evolving to transform from textual and pre-programmed commands to flexible and coordinated with the human brain [8]. In this context, brain waves are used to control robots, which are especially effective in noisy factory environments and when operators have other tasks at their disposal [9]. By sharing the necessary information between humans, robots, and the environment, in every way possible, accidents are less likely to occur, and machines can automatically avoid them before they happen [14]. The risk assessment of cooperation with robots in factories leads us to the point that the coexistence of humans and robots (machines) is desirable where robots need to replace some tasks that were previously performed by humans, and it is expected that robots in. Fields that have not been used before due to reliance on human power [14] should be used. It seems that the most prominent industries in which robotics are widely used include manufacturing, healthcare, agriculture, transportation, and logistics [1].

Today, the requirement of the industry is to move towards the engineering of intelligent flexible production systems with regard to resilience [47], a multifaceted capability of a system that includes avoidance (anticipation), tolerance (absorption), adaptation to (reconfiguration) and recovery(Repair) for expected and unexpected disturbances. For this reason, the cooperation and coexistence of man and machine increases the resilience of industries in cases such as the Covid-19 pandemic [15]. But in any case, detailed guidelines should be formulated and presented to the industry, which emphasizes the design of work and workplace with the aim of empowering and participation of all workers, according to the new conditions, so that workers can understand their competencies and develop with the development of robotics and play an active role in improving the production environment [48].

While in the perspective of the future, human-centeredness is the way forward for mankind to create stability and prosperity of the human race, there are also challenges. One of the challenges is the limitation of human physical strength in performing repetitive work tasks, and the other is the limited intellectual capacity of humans in cognition, holistic vision, power of prediction and reasoning for optimal decision making (in a short time and large amount of information). Therefore, humans still need support beyond their physical and intellectual limitations. Aiming for human-centeredness also leads us to consider various opportunities [29], one of which is the development of human-robot coexistence.

The Field of the Future

Despite the existing challenges, collaborative robots are expected to play an increasing role in industrial environments in the coming years. It seems that continuous advances and competition in the field of artificial intelligence and robotics, especially in 2024 and beyond, will lead to these robots becoming more affordable and efficient. In addition, as the awareness of the benefits of collaborative robots increases, also the desire to use them among companies will increase.

Conclusion

No matter how transformative technologies change and develop industrial robots, their basic goals remain the same: to improve quality, increase efficiency, reduce costs, and increase competitiveness through continuous optimization efforts [49]. But the implementation and integration of such complex socio-technical systems requires a comprehensive understanding of changes in the roles and responsibilities of workers, work design approaches and work systems, and the correct use of transformative technologies in Industry 4.0. To achieve this holistic understanding, it is important to identify and document the challenges and opportunities related to human work [34], and in this regard Industry 5.0 to complete and develop the remaining aspects of previous technological developments, in a human-centered and hybrid way. It is introduced from human-robot. While the benefits of using collaborative robots in industrial environments can be mentioned as increasing productivity, reducing costs, improving safety, increasing flexibility, and improving quality, there are also challenges, such as the cost of purchase and initial setup, integration with existing systems, concerns related to workers' jobs and moral issues caused by the dominance of robots over humans.

Ways to overcome the challenges can also be found in: attracting government support and development assistance, creating opportunities to adapt to these technologies, as well as investing in research and development to reduce the cost of collaborative robots, educating workers more about robots and how to work with them. They (to reduce concerns), increase the adoption of this technology in industry by relying on the human-centered aspects of Industry 5.0 and finally create ethical standards and clear guidelines for the development and use of collaborative robots with ethical issues in mind. In short, the widespread adoption of robotics technology brings both risks and benefits. Therefore, it is necessary to create appropriate ethical frameworks, change policies and self-regulation to reduce the risks and maximize the benefits of this technology. By understanding and addressing these challenges, we can better prepare for the inevitable integration of robotics and artificial intelligence into various aspects of our lives [1].

References

1. Licardo JT, Domjan M, Orehovački T (2024) Intelligent Robotics-A Systematic Review of Emerging Technologies and Trends. Electronics13(3): 542.
2. Goel R, Gupta P (2019) Robotics and Industry 4.0. A Roadmap to Industry 4.0: Smart Production, Sharp Business and Sustainable Development, pp: 157-169.
3. Lai R, Lin W, Wu Y (2018) Review of Research on the Key Technologies, Application Fields and Development Trends of Intelligent Robots. Intelligent Robotics and Applications, pp: 449-458.
4. Day CP (2018) Robotics in Industry-Their Role in Intelligent Manufacturing. Engineering 4(4): 440-445.
5. Evjemo LD, Gjerstad T, Grotli EI, Sziebig G (2020) Trends in Smart Manufacturing: Role of Humans and Industrial Robots in Smart Factories. Current Robotics Reports 1(2): 35-41.
6. Li S, Zheng P, Liu S, Wang Z, Wang V, et al. (2023) Proactive human-robot collaboration: Mutual-cognitive, predictable, and self-organising perspectives. Robotics and Computer-Integrated Manufacturing 81(81): 102510.
7. Ammar FS, Pierreval H, Elkosantini S (2017) A simulation-optimization based heuristic for the online assignment of multi-skilled workers subjected to fatigue in manufacturing systems. Computers & Industrial Engineering 112: 663-674.
8. Wang ML (2018) Brainwaves driven human-robot collaborative assembly. CIRP There are no sources in the current document. Annals 67(1): 13-16.
9. Gomez F, DelPreto J, Gil S, Guenther FH, Rus D (2017) Correcting robot mistakes in real time using EEG signals. IEEE International Conference on Robotics and Automation (ICRA).
10. Liu S, Wang XV, Wang L (2022) Digital twin-enabled advance execution for human-robot collaborative assembly. CIRP Annals 71(1): 25-28.
11. Liu S, Wang L, Gao RX (2024) Cognitive neuroscience and robotics: Advancements and future research directions. Robotics and Computer-Integrated Manufacturing 85: 102610.
12. Gao Z, Wanyama T, Singh I, Gadhrri A, Schmidt R (2020) From Industry 4.0 to Robotics 4.0-A Conceptual Framework for Collaborative and Intelligent Robotic Systems. Procedia Manufacturing 46: 591-599.
13. Simões C, Pinto A, Santos J, Pinheiro S, Romero D (2022) Designing human-robot collaboration (HRC) workspaces in industrial settings: A systematic literature review. Journal of Manufacturing Systems 62: 28-43.
14. Nakabo SHY, Furukawa Y, Ando N, Okuma T, Komoto H, et al. (2022) Digital Tools Integration and Human Resources Development for Smart Factories. International Journal of Automation Technology 16(3): 250-260.
15. Romero D, Stahre J (2021) Towards The Resilient Operator 5.0: The Future of Work in Smart Resilient Manufacturing Systems. Procedia CIRP 104: 1089-1094.
16. Günther J, Pilarski PM, Helfrich G, Shen H, Diepold K (2016) Intelligent laser welding through representation, prediction, and control learning: An architecture with deep neural networks and reinforcement learning. Mechatronics 34(34): 1-11.
17. Ma M, Lin W, Pan D, Lin Y, Wang P, et al. (2017) Data and Decision Intelligence for Human-in-the-Loop Cyber-Physical Systems: Reference Model, Recent Progresses and Challenges. Journal of Signal Processing Systems 90(8-9): 1167-1178.
18. Li HX, Si H (2017) Control for Intelligent Manufacturing: A Multiscale Challenge. Engineering 3(5): 608-615.
19. Zheng N, Liu Z, Ren P, Ma Y, Chen S, et al. (2017) Hybrid-augmented intelligence: collaboration and cognition. Frontiers of Information Technology & Electronic Engineering 18(2): 153-179.
20. Zhuang Y, Wu F, Chen C, Pan Y (2017) Challenges and opportunities: from big data to knowledge in AI 2.0.

Frontiers of Information Technology & Electronic Engineering 18(1): 3-14.

21. Ulhoi JP, Norskov S (2022) The emergence of social robots: Adding physicality and agency to technology. Journal of Engineering and Technology Management 65: 101703.
22. Arduengo M, Sentis L (2020) The Robot Economy: Here It Comes. International Journal of Social Robotics 13: 937-947.
23. Majumdar, Pavone M (2019) How Should a Robot Assess Risk? Towards an Axiomatic Theory of Risk in Robotics. Springer Proceedings in Advanced Robotics, pp: 75-84.
24. Zhou J, Zhou Y, Wang B, Zang J (2019) Human-Cyber-Physical Systems (HCPSs) in the Context of New-Generation Intelligent Manufacturing. Engineering 5(4): 624-636.
25. Davis J, Edgar T, Porter J, Bernaden J, Sarli M (2012) Smart manufacturing, manufacturing intelligence and demand-dynamic performance. Computers & Chemical Engineering 47: 145-156.
26. Mekid S, Pruschek P, Hernandez J (2009) Beyond intelligent manufacturing: A new generation of flexible intelligent NC machines. Mechanism and Machine Theory 44(2): 466-476.
27. Ansari F, Erol S, Sihn W (2018) Rethinking Human-Machine Learning in Industry 4.0: How Does the Paradigm Shift Treat the Role of Human Learning? Procedia Manufacturing 23(23): 117-122.
28. Kuschan J, Krüger J (2021) Fatigue recognition in overhead assembly based on a soft robotic exosuit for worker assistance. CIRP Annals 70(1): 9-12.
29. Wang L (2022) A futuristic perspective on human-centric assembly. Journal of Manufacturing Systems 62: 199-201.
30. Zhou Z, Liu J, Pham TD, Xu W, Ramirez FJ, et al. (2018) Disassembly sequence planning: Recent developments and future trends. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 233(5): 1450-1471.
31. Semeraro F, Griffiths A, Cangelosi A (2023) Human–robot collaboration and machine learning: A systematic review of recent research. Robotics and Computer-Integrated Manufacturing 79: 102432.
32. DGRI (2021) Industry 5.0-Towards a sustainable, human-centric and resilient European industry.
33. Inagaki T (2003) Adaptive Automation: Sharing and Trading of Control. The Proceedings of the Transportation and Logistics Conference10: 79-84.
34. Kadir A, Broberg O, Conceição CS (2019) Current research and future perspectives on human factors and ergonomics in Industry 4.0. Computers & Industrial Engineering 137: 106004.
35. Kasaei HS, Melsen J, Beers FV, Steenkist C, Voncina K (2021) The State of Lifelong Learning in Service Robots. Journal of Intelligent and Robotic Systems 103(1).
36. Sheridan TB (2016) Human-Robot Interaction. Human Factors: The Journal of the Human Factors and Ergonomics Society 58(4): 525-532.
37. Osawa H (2017) Analysis of robot hotel: Reconstruction of works with robots. IEEE Xplore.
38. Kantur, Say ISA (2012) Organizational resilience: A conceptual integrative framework. Journal of Management & Organization 18(6): 762-773.
39. Busnaina A, Mead J, Isaacs J, Somu S (2013) Nanomanufacturing and sustainability: opportunities and challenges. Springer eBooks 1: 331-336.
40. Esmaeilian, Behdad S, Wang B (2016) The evolution and future of manufacturing: A review. Journal of Manufacturing Systems 39(39): 79-100.
41. Pan Y (2016) Heading toward Artificial Intelligence 2.0. Engineering 2(4): 409-413.
42. Nunes S, Zhang P, Silva SJ (2015) A Survey on Human-in-the-Loop Applications Towards an Internet of All. IEEE Communications Surveys Tutorials 17(2): 944-965.
43. Marcinkowski FM, Davis C (2018) Cyber-human systems of thought and understanding," Journal of the Association for Information Science and Technology 70(04).
44. Pacaux-Lemoine MP, Berdal Q, Enjalbert S, Trentesaux D (2018) Towards human-based industrial cyber-physical systems. IEEE Industrial Cyber-Physical Systems.
45. Zhong RY, Xu X, Klotz E, Newman ST (2019) Intelligent Manufacturing in the Context of Industry 4.0: A Review. Engineering 3(5): 616-630.
46. Weber RH (2010) Internet of Things- New security and privacy challenges. Computer Law & Security Review 26(1): 23-30.
47. Madni M, Jackson S (2018) Towards a Conceptual Framework for Resilience Engineering. IEEE Systems

Journal 3(2): 181-191.

48. Kaasinen, Schmalfuß F, Ozturk C, Aromaa S, Boubekeur M, et al. (2020) Empowering and engaging industrial workers with Operator 4.0 solutions. Computers & Industrial Engineering 139(105678): 105678.

49. Nunes D, Silva JS, Boavida F (2024) A Practical Introduction to Human-in-the-Loop Cyber-Physical Systems. John Wiley & Sons.