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Editorial

Recent Advanced Applications of Virtual Industrial Informatics and Robotics

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1. Special Issue Summary

In recent years, there has been a concerted effort to revolutionize industrial production through the integration of digital technologies, leading to the emergence of Industry 4.0 and to the upcoming fifth societal revolution (Society 5.0). Key technologies driving this revolution include, among others, artificial intelligence (AI), virtual/augmented reality (VR/AR), the Internet of Things (IoT), automation, 5G, and robotics. The current progress in innovative algorithms, computational resources, and the profusion of industrial-scale big data resulting from the growing digitalization of various systems, processes, and interactions has collectively ushered in a transformative era in the application of these key technologies. The field of industrial informatics is placed at the intersection of these technologies and manufacturing, providing opportunities to develop sophisticated systems for planning and managing manufacturing processes. Furthermore, immersive technologies like VR and AR offer new ways to improve operations by enabling human–machine collaboration (HMC) [1], while mobile robots are becoming more versatile and able to work alongside human operators. This Special Issue focuses on manufacturing technologies that include the use of modern methods and tools to develop innovative applications that leverage informatics, immersive technologies, and robotic solutions to enhance industrial processes.

Modern industrial cyber-physical systems (ICPSs), characterized by extensive integration of sensors and actuators across geographically dispersed locations [2], necessitate real-time distributed monitoring and control [3]. However, challenges arise due to geographic dispersion affecting distributed sensing, control, and optimization. Communication limitations, such as security vulnerabilities as well as bandwidth and network reachability-related issues, further impact system performance, necessitating the integration of machine learning technologies to address these challenges effectively [4].

The synergy between the digital twin and the Internet of Things (IoT) is critical to harnessing information effectively without compromising security. While IoT forms the backbone, a digital twin represents a real-time virtual replica of an object or system [5], utilizing reasoning, simulation, and machine learning for comprehensive analysis. IoT's network connectivity to physical devices allows data processing and action [6], making it an essential component contributing to the realization of digital twins, particularly with the increasing prevalence of IoT devices [7].

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Augmented reality (AR), virtual reality (VR), mixed reality (MR), and extended reality (often abbreviated as XR) are key terms that are frequently utilized in order to describe how cutting-edge digital technologies either generate or modify reality [8]. Nonetheless, in both academic and professional contexts, there exists inconsistency in their usage, leading to conceptual confusion and ambiguous boundaries. Drawing on prior research and insights from XR professionals, in this Special Issue, the contributors present a discussion on the definitions and meanings of these terms. This analysis leads us to the following conclusions:

1. XR should signify an open approach, with the designation of X implying the unknown variable (xReality) rather than solely extended reality.
2. AR experiences can be described on a continuum ranging from assisted reality to mixed reality, based on the level of local presence.
3. AR and VR should be regarded as distinct experiences due to fundamental differences.

In the realm of industrial robotics, collaborative solutions are emerging as a new frontier, allowing seamless sharing of skills between human workers and robots, leveraging the strengths of both [9]. Despite the immense potential, achieving efficient human–robot collaboration requires addressing challenges related to safe interactions [10], intuitive user interfaces, and efficient programming [11]. The survey paper extensively reviews human–robot collaboration in industrial environments, focusing on physical and cognitive interaction issues, presenting available solutions, discussing key industrial applications, and highlighting areas for further development [12].

2. Summary of the Special Issue Research Works

The goal of the first contribution is to provide a literature review of the academic research on industrial informatics, a scientific field focused on automating industrial design and manufacturing using data-based technologies such as Data Science, Big Data, and artificial intelligence. The research conducted using bibliometric analysis and text mining found that the thematic groups related to industrial informatics are the Internet of Things, machine learning, engineering education, cyber-physical systems, and embedded systems. China, Germany, and Brazil are found to be the countries that dominate research in industrial computing. The study concludes that industrial informatics research is shifting towards the application of intelligent methods such as machine learning and Big Data to create new methods and tools.

The authors of the second research paper deal with the use of unmanned aerial vehicles (UAVs) for inventory management in large enterprises, which is a common practice, particularly in tasks that are high-risk and require quick action. The advantages of using UAVs over other unmanned systems include independent movement and onboard cameras. This paper proposes the development of a supervisory control and data acquisition (SCADA) system for inventory management of logistics companies using drones, evaluating communication protocols and infrared technology to recognize merchandise availability. The system allows real-time monitoring of inventory and integration into a smart city environment.

The third contribution by Fakhri et al. (2023) presents a systematic approach to achieve stable grasping of objects using a two-finger robotic hand filled with granular media. The stiffness of the finger was adjusted by controlling the compaction of the media with vacuum pressure. The paper analyzed grasping stability under the effects of external torque and vacuum pressure. Experimental control schemes were implemented to ensure the effectiveness of grasping. Next, results showed the existence of stable and unstable grasping regions for each combination of applied torque and vacuum pressure. The two-finger robotic hand has potential for further improvement to carry higher loads.

Moving on to the fourth research paper contribution, electromechanical systems created using Simulink or Ptolemy are widely used in the autonomous systems and robotics industries, making it crucial to ensure their safety and security. Test-case generation technologies are commonly used for this purpose. However, traditional methods like model-checking and search-based techniques have limitations. Recently, coverage-guided fuzzing has shown efficacy for generating test cases, and in this paper, the authors propose an integration technology (SPsCGF) that combines bounded model checking and fuzzing to increase model coverage and efficiency. The results show that SPsCGF outperforms state-of-the-art work in terms of coverage and time efficiency.

The authors of the fifth contribution suggest a new algorithm for planning robotic manipulator trajectories that ensures motion smoothness by using the fourth-order S-curve. It can keep the acceleration and jerk in a saturated state, which improves efficiency without involving optimization processes. The algorithm also contains a multi-axis synchronization planning algorithm to enhance motion stability. The proposed trajectory planning algorithm can generate jerk-continuous rather than just acceleration-continuous trajectories, which is an improvement over the previous method. Polynomial equations are utilized to generate kinematically constrained, real-time motion control of robots, and no optimization procedures are required.

Staying in the field of industrial robots, the winding process of carbon fiber has not been extensively studied when it comes to tensioning and winding complex shapes. Therefore, the main objective of the fifth SI contribution is to investigate the possibility of using two industrial robots connected as master and slave to wind carbon fiber with an automatic fiber tensioning tool. The robots' trajectory is adjusted using a force transducer to maintain constant tension for the fiber windings. Experimental tests have shown that this method can create compact structures of constantly tensioned fiber bundles with variable tension in molds with complex shapes.

Next, the authors of the sixth contribution deal with the increasing number of wireless applications requiring more spectrum bands. However, by the time it is difficult to adapt them to new applications, the crowded spectrum affects the quality of service. Cognitive radio is a promising technology to address spectrum scarcity by using spectrum sensing to allocate the spectrum to secondary users when primary users are not using it. In this paper, a novel 5G spectrum sensing technique was implemented using a hybrid matched filter algorithm, which was found to perform more effectively than the traditional matched filter in both Rayleigh and Rician channels.

Moving on to the field of artificial intelligence (AI), the seventh contribution [8] discusses adversarial attacks on deep neural network models and various defense methods that have been proposed. A Noise-Fusion Method (NFM) is introduced as a simple and effective defense mechanism that adds noise to the model input at both training and run time. The NFM is evaluated against three different attacks on two datasets using various statistical distributions of amplitude noises. The results show that the NFM not only defends against all three attacks but also improves the robustness of the models. The NFM has the potential to be applied to models with audio or voice input.

Finally, the last research paper discusses the use of virtual reality (VR) technology in combination with intelligent chatbots to provide enhanced customer service in industries such as engineering and manufacturing. The researchers developed a framework for a VR-enabled chatbot system that focuses on large industrial power transformer mass-customization. The system utilizes machine learning to provide natural language understanding and answer retrieval for frequently asked questions. The VR visuals provide immersive 3D images to support real-time design consultation. This new system provides a strategic advantage for industries seeking to improve customer service and overall efficiency.

In the first review paper of this SI, Voinea et al. (2023) investigate the emergence of industrial augmented reality (IAR) and its potential to transform different industries by combining digital information with the real world. It presents a literature review analysis of IAR studies from 2018 to 2022, identifying ten trending topics in AR application, including Industry 4.0, artificial intelligence, smart manufacturing, industrial robots, digital twin, assembly, the Internet of Things, visualization, maintenance, and training. The paper provides a detailed overview of each trend, discussing their existing applications and research directions.

Next, Mourtzis et al. (2021) deal with smart manufacturing and 5G technology in Industry 4.0. Communication latency remains a significant barrier for many applications in manufacturing networks, despite the development of improved communication protocols and standards during Industry 4.0. The Tactile Internet (TI), which utilizes 5G and beyond communications, has high availability, security, and ultra-low latency, making it the next evolutionary step for the Internet of Things (IoT). The TI is expected to bring about significant changes toward Society 5.0 and address complex issues in current society. The 5G mobile communication systems will support the TI at the wireless edge, enabling ultra-reliable low-latency applications such as smart manufacturing, virtual reality, and augmented reality. The paper aims to present the current state of 5G and TI, challenges and future trends for 5G networks beyond 2021, and a conceptual framework for integrating 5G and TI into existing industrial case studies. The key enabling technologies of TI and the beyond 5G era toward Society 5.0 are also summarized and discussed.

Enhanced AI, VR/AR, IoT, automation, 5G, and robotics can be attained across various levels and within nearly any system, as evident from the contributions in this Special Issue. Although several challenges persist, research and technology stand as essential tools for surmounting the hurdles presented in industrial informatics and robotics, particularly in the context of environmentally responsible, ethical, and safe use. Future research endeavors must prioritize the establishment of standards, guidelines, and ethical policies within the field of industrial informatics and robotics to guarantee the reliability, safety, and accountability of the abovementioned technologies. Industrial informatics and robotics assume a pivotal role in providing opportunities to develop advanced systems for planning and managing manufacturing processes. Consequently, through incremental advancements, the goal is to reinforce the role of innovation, with the objective of addressing forthcoming challenges with efficient solutions that also ensure economical, dependable, and sustainable manufacturing.

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List of Contributions

1. Pejić Bach, M.; Ivec, A.; Hrman, D. Industrial Informatics: Emerging Trends and Applications in the Era of Big Data and AI. *Electronics* **2023**, *12*, 2238. https://doi.org/10.3390/electronics12102238.
2. Salazar, F.; Martínez-García, M.S.; de Castro, A.; Chávez-Fuentes, C.; Cazorla, M.; Ureña-Aguirre, J.d.P.; Altamirano, S. UAVs for Business Adoptions in Smart City Environments: Inventory Management System. *Electronics* **2023**, *12*, 2090. https://doi.org/10.3390/electronics12092090.
3. Fakhri, O.; Youssef, G.; Nacy, S.; Jameel Al-Tamimi, A.N.; Hussein, O.; Abbood, W.T.; Abdullah, O.I.; AL-Karkhi, N.K. A Systematic Approach to Stable Grasping of a Two-Finger Robotic Hand Activated by Jamming of Granular Media. *Electronics* **2023**, *12*, 1902. https://doi.org/10.3390/electronics12081902.
4. Yang, Y. Improve Model Testing by Integrating Bounded Model Checking and Coverage Guided Fuzzing. *Electronics* **2023**, *12*, 1573. https://doi.org/10.3390/electronics12071573.
5. Wu, G.; Zhang, N. Kinematically Constrained Jerk–Continuous S-Curve Trajectory Planning in Joint Space for Industrial Robots. *Electronics* **2023**, *12*, 1135. https://doi.org/10.3390/electronics12051135.
6. Sbanca, M.P.; Boboc, R.G.; Mogan, G.L. Fiber Tensioning Systems in a Robotized Winding Procedure for Composite Materials Building Processes. *Electronics* **2023**, *12*, 254. https://doi.org/10.3390/electronics12020254.

7. Kumar, A.; Venkatesh, J.; Gaur, N.; Alsharif, M.H.; Jahid, A.; Raju, K. Analysis of Hybrid Spectrum Sensing for 5G and 6G Waveforms. *Electronics* **2023**, *12*, 138. https://doi.org/10.3390/electronics12010138.
8. Shi, L.; Liao, T.; He, J. Defending Adversarial Attacks against DNN Image Classification Models by a Noise-Fusion Method. *Electronics* **2022**, *11*, 1814. https://doi.org/10.3390/electronics11121814.
9. Trappey, A.J.C.; Trappey, C.V.; Chao, M.-H.; Hong, N.-J.; Wu, C.-T. A VR-Enabled Chatbot Supporting Design and Manufacturing of Large and Complex Power Transformers. *Electronics* **2022**, *11*, 87. https://doi.org/10.3390/electronics11010087.
10. Voinea, G.-D.; Gîrbacia, F.; Duguleană, M.; Boboc, R.G.; Gheorghe, C. Mapping the Emergent Trends in Industrial Augmented Reality. *Electronics* **2023**, *12*, 1719. https://doi.org/10.3390/electronics12071719.
11. Mourtzis, D.; Angelopoulos, J.; Panopoulos, N. Smart Manufacturing and Tactile Internet Based on 5G in Industry 4.0: Challenges, Applications and New Trends. *Electronics* **2021**, *10*, 3175. https://doi.org/10.3390/electronics10243175.

References

1. Xiong, Y.; Tang, Y.; Kim, S.; Rosen, D.W. Human-Machine Collaborative Additive Manufacturing. *J. Manuf. Syst.* **2023**, *66*, 82–91. [CrossRef]
2. Liu, J.; Zhang, W.; Ma, T.; Tang, Z.; Xie, Y.; Gui, W.; Niyoyita, J.P. Toward Security Monitoring of Industrial Cyber-Physical Systems via Hierarchically Distributed Intrusion Detection. *Expert Syst. Appl.* **2020**, *158*, 113578. [CrossRef]
3. Zhou, J.; Li, L.; Vajdi, A.; Zhou, X.; Wu, Z. Temperature-Constrained Reliability Optimization of Industrial Cyber-Physical Systems Using Machine Learning and Feedback Control. *IEEE Trans. Autom. Sci. Eng.* **2023**, *20*, 20–31. [CrossRef]
4. Han, Q.-L.; Ding, D.; Ge, X. New Trends of Artificial-Intelligence-Based Control, Filtering, and Optimization for Industrial Cyber-Physical Systems. *Inf. Sci.* **2023**, *648*, 119333. [CrossRef]
5. López, C.E.B. Real-Time Event-Based Platform for the Development of Digital Twin Applications. *Int. J. Adv. Manuf. Technol.* **2021**, *116*, 835–845. [CrossRef]
6. Ahsan, M.; Based, M.A.; Haider, J.; Rodrigues, E.M. Smart Monitoring and Controlling of Appliances Using LoRa Based IoT System. *Designs* **2021**, *5*, 17. [CrossRef]
7. Nalini, M.; Bharathkumar, M.R.; Keerthivasan, R.; Nithyashree, N.; Dhanashree, V. Chapter 10–Impact of Internet of Things and Digital Twin on Manufacturing Era. In *Digital Twin for Smart Manufacturing*; Dhanaraj, R.K., Bashir, A.K., Rajasekar, V., Balusamy, B., Malik, P., Eds.; Academic Press: Cambridge, MA, USA, 2023; pp. 185–202. ISBN 978-0-323-99205-3.
8. Mourtzis, D.; Siatras, V.; Angelopoulos, J. Real-Time Remote Maintenance Support Based on Augmented Reality (AR). *Appl. Sci.* **2020**, *10*, 1855. [CrossRef]
9. Vicentini, F. Collaborative Robotics: A Survey. *J. Mech. Des.* **2021**, *143*, 040802. [CrossRef]
10. Mukherjee, D.; Gupta, K.; Chang, L.H.; Najjaran, H. A Survey of Robot Learning Strategies for Human-Robot Collaboration in Industrial Settings. *Robot. Comput.-Integr. Manuf.* **2022**, *73*, 102231. [CrossRef]
11. Proia, S.; Carli, R.; Cavone, G.; Dotoli, M. Control Techniques for Safe, Ergonomic, and Efficient Human-Robot Collaboration in the Digital Industry: A Survey. *IEEE Trans. Autom. Sci. Eng.* **2022**, *19*, 1798–1819. [CrossRef]
12. Villani, V.; Pini, F.; Leali, F.; Secchi, C. Survey on Human–Robot Collaboration in Industrial Settings: Safety, Intuitive Interfaces and Applications. *Mechatronics* **2018**, *55*, 248–266. [CrossRef]