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Editorial

Closing Editorial: Advances and Future Directions in Autonomous Systems for Cyber–Physical Systems and Smart Industry

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1. Introduction

The rapid evolution of autonomous systems and their integration into cyber–physical Systems (CPS) and the Industrial Internet of Things (IIoT) has been a critical driver of the fourth industrial revolution, also known as Industry 4.0 [1], along with the transition towards Industry 5.0. These systems enable the real-time monitoring, control, and optimization of industrial processes by combining the power of computational intelligence with physical machinery. Autonomous systems offer significant potential for improving efficiency, flexibility, and sustainability in various industrial sectors. However, challenges remain, including interoperability, real-time data processing, and secure communication across heterogeneous devices and networks.

Recent advancements in artificial intelligence (AI) [2], edge computing, advanced cyber security, and industrial automation have opened new avenues for innovation in CPS and smart industry. These innovations are driving the development of intelligent decision-making systems capable of self-managing the complexity and scale of modern industrial environments [3]. This Special Issue focuses on exploring the innovations and challenges in autonomous systems, aiming to bridge gaps in current knowledge and foster future research. The contributions to this Special Issue provide a comprehensive overview of the current state of the field while addressing critical challenges. The list of contributions follows.

1. Burillo, F.; Lambán, M.; Royo, J.; Morella, P.; Sánchez, J. Real-Time Production Scheduling and Industrial Sonar and Their Application in Autonomous Mobile Robots. *Appl. Sci.* **2024**, *14*, 1890. https://doi.org/10.3390/app14051890.
2. Serôdio, C.; Mestre, P.; Cabral, J.; Gomes, M.; Branco, F. Software and Architecture Orchestration for Process Control in Industry 4.0 Enabled by Cyber-Physical Systems Technologies. *Appl. Sci.* **2024**, *14*, 2160. https://doi.org/10.3390/app14052160.
3. Borah, S.; Khanal, A.; Sundaravadivel, P. Emerging Technologies for Automation in Environmental Sensing: Review. *Appl. Sci.* **2024**, *14*, 3531. https://doi.org/10.3390/app14083531.
4. Monteiro, P.; Pereira, R.; Nunes, R.; Reis, A.; Pinto, T. Context-Aware System for Information Flow Management in Factories of the Future. *Appl. Sci.* **2024**, *14*, 3907. https://doi.org/10.3390/app14093907.
5. Gonzalez-Santocildes, A.; Vazquez, J.; Eguiluz, A. Enhancing Robot Behavior with EEG, Reinforcement Learning and Beyond: A Review of Techniques in Collaborative Robotics. *Appl. Sci.* **2024**, *14*, 6345. https://doi.org/10.3390/app14146345.

Citation: Pinto, R.; Torres, P.M.B.; Lohweg, V. Closing Editorial: Advances and Future Directions in Autonomous Systems for Cyber–Physical Systems and Smart Industry. *Appl. Sci.* **2024**, *14*, 10673. https://doi.org/10.3390/app142210673

Received: 6 November 2024
Accepted: 16 November 2024
Published: 19 November 2024

6. Sagar, A.; Islam, M.; Haider, A.; Kim, H. Uncertainty-Aware Federated Reinforcement Learning for Optimizing Accuracy and Energy in Heterogeneous Industrial IoT. *Appl. Sci.* **2024**, *14*, 8299; https://doi.org/10.3390/app14188299.
7. Łach, Ł.; Svyetlichnyy, D. Comprehensive Review of Traffic Modeling: Towards Autonomous Vehicles. *Appl. Sci.* **2024**, *14*, 8456. https://doi.org/10.3390/app14188456.

2. An Overview of the Published Contributions

This Special Issue presents a diverse set of contributions that explore the innovations and challenges of integrating autonomous systems within CPS and smart industrial environments. The selected papers span a wide range of research areas, from real-time production scheduling and industrial robotics to human–robot collaboration and traffic modeling for autonomous vehicles. Collectively, these contributions demonstrate the critical role that autonomous systems play in optimizing industrial processes, improving decision making, and enhancing the efficiency of smart environments.

This Special Issue features seven contributions that explore innovations and challenges in autonomous systems for CPS and smart industry. Each of these papers addresses significant challenges within their respective areas, emphasizing the interdisciplinary nature of research in autonomous systems. By examining a wide range of applications—from real-time production scheduling to human–robot collaboration and environmental sensing—these contributions illustrate how autonomous systems are transforming industrial and environmental processes. Table 1 summarizes the key aspects of each contribution.

Table 1. Analysis of the published contributions to this Special Issue.

Contribution	Research Area	Focus	Research Type	Organization/Industry
Contribution 1: Burillo et al. (2024)	Autonomous Mobile Robots	Real-time production scheduling and integration of industrial sonar for adaptive navigation and obstacle detection	Applied Research	Industrial Robotics and Manufacturing Systems
Contribution 2: Serôdio et al. (2024)	CPS in Industry 4.0	Software and architecture orchestration for enhanced process control and logistics using CPS technologies	Theoretical and Applied Research	Process Control and Automation Industry
Contribution 3: Borah et al. (2024)	Environmental Sensing Automation	Review of emerging automation technologies in environmental sensing, focusing on UAVs, smart agriculture, and robotics	Review	Environmental Monitoring and Smart Agriculture
Contribution 4: Monteiro et al. (2024)	Context-Aware Systems	Context engine for managing information flow in future factories, with applications for decision-making and alert systems	Applied Research	Smart Factories and Information Management Systems

Table 1. *Cont.*

Contribution	Research Area	Focus	Research Type	Organization/Industry
Contribution 5: Gonzalez-Santocildes et al. (2024)	Collaborative Robotics	Review of techniques such as EEG and reinforcement learning to enhance human–robot collaboration and safety	Review	Human–Robot Collaboration in Industrial and Medical Applications
Contribution 6: Sagar et al. (2024)	Industrial IoT Optimization	Federated reinforcement learning for optimizing accuracy and energy consumption in heterogeneous industrial IoT networks	Applied Research	Industrial IoT Systems and Energy Optimization
Contribution 7: Łach and Svyetlichnyy (2024)	Autonomous Vehicles	Comprehensive review of traffic modeling approaches relevant to autonomous vehicles, including AV–human interaction and mixed traffic modeling	Review	Autonomous Vehicle Industry and Traffic Management

The first contribution by Burillo et al. introduces a novel real-time production scheduling system enhanced by industrial sonar technology. Their approach focuses on improving the navigation and obstacle-detection capabilities of autonomous mobile robots (AMRs) within complex manufacturing environments [4]. By utilizing bidirectional communication between work centers and agile scheduling algorithms, this work addresses the dynamic challenges of production scheduling, such as machine malfunctions or material delays, offering an adaptive and responsive solution for minimizing production downtime.

Serôdio et al.'s contribution explores the orchestration of software and architecture for process control in Industry 4.0, enabled by CPS technologies. This paper emphasizes the importance of interoperability between information technology (IT) and operational technology (OT) systems. It presents a comprehensive framework that integrates CPS, service-oriented architectures (SOA) [5], and real-time data acquisition for logistics and asset tracking. The proposed architecture highlights the potential of CPS to transform manufacturing by enabling fully interconnected, autonomous systems capable of real-time decision making.

In a detailed review, Borah et al. examine the emerging technologies that are transforming automation in environmental sensing. The authors cover a range of applications, including unmanned aerial systems (UAS) [6], smart agriculture, and environmental robotics, providing a comprehensive analysis of how automation technologies are enhancing data collection and monitoring. Despite significant advancements, the review highlights several challenges, including interoperability, system scalability, and cost, suggesting the need for continued research in these areas to fully realize the potential of automation in environmental sensing.

Monteiro et al. contribute a context-aware system for managing information flow in smart factories. Their work introduces the "Context Engine", a microservices-based application designed to enhance decision-making and alert systems within factories of the future. The system enables real-time monitoring and contextualized responses to production changes, offering a flexible and scalable solution that can integrate with various factory applications and devices. The case studies provided in this work demonstrate the practical application of the context engine in optimizing factory operations and supporting worker decision making.

Gonzalez-Santocildes et al. provide a comprehensive review of techniques for enhancing robot behavior in collaborative robotics, focusing on the integration of EEG data and reinforcement learning. The paper highlights the growing importance of human–robot collaboration (HRC) in industrial settings and examines how brain activity monitoring and reinforcement learning can be applied to improve robot decision making and safety in real-time interactions with humans. This review also outlines the future research directions necessary to advance HRC, particularly in terms of ensuring intuitive and emotionally aware interactions between robots and human operators.

Sagar et al. address the optimization of energy consumption and accuracy in industrial IoT systems through an innovative Uncertainty-Aware Federated Reinforcement Learning (UA-FedRL) approach. Their work proposes a predictive weighted average aggregation technique that improves the performance of federated learning models in heterogeneous IoT environments. The ability to dynamically manage resource-constrained devices and maintain high levels of accuracy under non-ideal conditions is a significant step toward making federated learning feasible for real-world industrial applications.

Finally, Łach and Svyetlichnyy present a comprehensive review of traffic modeling techniques relevant to autonomous vehicles (AVs). Their paper explores various modeling approaches—microscopic, macroscopic, and mesoscopic—that are used to simulate the behavior of AVs and analyze traffic dynamics in mixed environments where both human-driven and autonomous vehicles coexist. The review identifies critical challenges in integrating AVs into existing transportation infrastructures and highlights the potential of advanced traffic modeling to optimize the flow and safety of future autonomous transportation systems [7].

Taken together, these papers address critical technical challenges in the development and deployment of autonomous systems within CPS and smart industries. From real-time scheduling in manufacturing to the integration of human–robot collaboration techniques, the contributions to this Special Issue highlight the transformative potential of autonomous systems. Moreover, they provide a solid foundation for future research, aimed at further advancing the capabilities of autonomous systems in both industrial and environmental contexts.

3. Conclusions

The innovations presented in this Special Issue contribute significantly to the understanding and development of autonomous systems for CPS and smart industry. Despite the advances made, several key challenges remain that warrant further exploration. Among these are the need for robust real-time systems that can operate in highly dynamic and unpredictable environments, as well as the ongoing challenge of ensuring seamless interoperability between diverse systems and devices.

Each of these contributions highlights the importance of addressing specific technical challenges in the development of autonomous systems, whether it be optimizing resource management, enhancing decision-making processes, or improving human–machine collaboration. These papers collectively emphasize the ongoing need for interdisciplinary research, integrating insights from robotics, artificial intelligence, and industrial automation.

Looking forward, future research should focus on enhancing the adaptability of autonomous systems, particularly in terms of real-time data processing and decision making. The integration of edge computing and AI-driven autonomous control systems will be critical in overcoming many of the current limitations. Moreover, there is a need to explore more effective ways to manage the security and privacy concerns that arise as these systems become more interconnected and widely adopted in critical infrastructure.

We hope that the contributions to this Special Issue serve as a foundation for further innovation in this exciting field. The future of autonomous systems in CPS and smart industry holds immense potential, and we look forward to seeing how these technologies will continue to evolve in the coming years.

Author Contributions: Conceptualization, R.P.; methodology, R.P.; formal analysis, R.P.; investigation, R.P.; data curation, R.P.; writing—original draft preparation, R.P.; writing—review and editing, R.P., P.M.B.T., and V.L.; visualization, R.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: As guest editors of the Special Issue "Autonomous Systems in Cyber–Physical Systems and Smart Industry: Innovations and Challenges", we would like to express our deep appreciation to all the authors whose work was published in this issue and thus contributed to its success.

Conflicts of Interest: The authors declare no conflicts of interest.

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Short Biography of Authors

Rui Pinto is an integrated researcher at SYSTEC - Research Center for Systems and Technologies and ARISE – Advanced Production and Intelligent Systems Associated Laboratory. He is also an invited teaching assistant at the Faculty of Engineering of the University of Porto (FEUP). With numerous publications and extensive experience supervising thesis projects, Rui Pinto specializes in Cyber-Physical Systems (CPS), IoT, and Industry 4.0. His research focuses on digitalization of industrial processes, robotics, and data analytics in manufacturing, and extends to knowledge and technology transfer initiatives, particularly in collaborative research projects. A member of both ACM and IEEE, Rui Pinto actively contributes to advancing intelligent systems and smart manufacturing.

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Volker Lohweg is the head of the research group "Discrete Systems" and Executive Board Member of the Institute Industrial IT (inIT). The research group's working area is dedicated to Cognitive Systems in automation especially Information Fusion and Optical Document Security as well as in medical and health technologies. He is active in SPIE and IEEE as a reviewer for image processing and data analysis. His actual interests are sensory conflict modelling and Multi-Scale signal analysis based on Sustainable AI and Machine Learning.