Overview of AI4DT&CP@IJCAI 2024: The Second Workshop on AI for Digital Twins and Cyber-Physical Applications*

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Abstract

The 2024 Workshop on AI for Digital Twins and Cyber-Physical Applications (AI4DT&CP 2024) is at its second edition, held in conjunction with IJCAI 2024: the 33rd International Joint Conference on Artificial Intelligence in Jeju (South Korea). The workshop seeks to gather experts in Artificial Intelligence, Digital Twin technology, and Cyber-Physical Systems to explore the latest innovations and best practices in applying AI-driven digital twins across various cyber-physical services and applications. The discussions will cover recent trends, research projects, and emerging developments in Digital Twins and Artificial Intelligence, focusing on how these advancements address cyber-physical applications from diverse perspectives.

Keywords

Artificial Intelligence, Cyber-physical, Digital Twins, Internet of Things

1. Introduction

The widespread accessibility of easy-to-deploy sensors and the significant progress in Internet of Things (IoT) technology have led to new intelligent applications that effortlessly integrate the physical and digital realms. Notwithstanding this trend, there are still open issues. A major one, is dealing with the complexity of the physical world to develop and deploy intelligent services that continuously perceive and learn from data coming from the environment. This issue has renewed interest in Digital Twin technology, which allows for the development of virtual replicas of physical objects by replicating their properties, data, and behaviors [1]. This technology unlocks new intelligent and augmented functionalities, including learning, modeling, simulation, and cognitive capabilities. Artificial Intelligence (AI) is poised to revolutionize Digital

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Twin technology by facilitating the creation of intelligent virtual counterparts that can deliver smart services and contribute to adaptive AI within cyber-physical systems [2]. Furthermore, integrating deep learning models into digital twin systems hides new challenges, especially when monitoring or controlling critical systems [3]. Machine Learning Operations (MLOps) approaches are attracting increasing interest to ensure that intelligent models are deployed robustly and reliably, especially when exploiting Continual Learning or Reinforcement Learning techniques [4]. To tackle these challenges, it is essential to introduce new techniques and methods while exploring the latest advancements and best practices in applying AI-driven digital twins across diverse cyber-physical services and applications.

2. AI for Digital Twin

AI can be used to enhance the performance, safety, and security of Digital Twin and IoT-based cyber-physical systems by making them more intelligent, adaptive, and autonomous. The results can be better control, optimization, and prediction of the Cyber-Physical systems [5].

Digital Twin and cyber-physical systems can be enhanced with AI in several ways since AI enables real-time monitoring and control of physical systems with the possibility of delivering intelligent services with applications in several domains, such as:

1. **Predictive modelling**: AI-powered digital twins can predict the behaviour of IoT-based physical systems under different conditions, helping to identify potential issues or inefficiencies in the physical system before they occur [6, 7].
2. **Anomaly detection**: AI-powered digital twins can analyse sensor data from the physical system in real-time, using machine learning techniques to identify anomalies or deviations from normal behaviour [8].
3. **Digital Human Replica**: Building virtual replicas of humans that reproduce and model both outer and inner aspects of a human being, such as physical and physiological characteristics, personality, sensitivities, thoughts, and skills [9].
4. **Optimization**: AI-powered digital twins can analyse sensor data and other inputs to optimise the performance of the physical system (e.g., by adjusting the control parameters to minimise energy consumption or maximise production efficiency) [10, 11].
5. **Autonomous control**: AI-powered digital twins can be used to control a IoT-based physical system autonomously, using sensor data and other inputs to make real-time decisions [3].
6. **Safety and security**: AI-powered digital twins can be used to monitor and analyse sensor data to detect security threats or unsafe conditions in the physical system and to trigger appropriate responses [12].

At the same time, incorporating machine learning models into digital twin systems can be critical when monitoring or controlling critical systems. Machine Learning Operations (**MLOps**) approaches are attracting increasing interest to ensure that intelligent models are deployed robustly and reliably, especially when exploiting **Continual Learning** or **Reinforcement Learning** technique [11].

3. Topics of interest

Topics of interest include, but are not limited to, the following:

- What-if scenarios with IoT-based Cyber-Physical applications
- MLOps in Cyber-Physical systems
- Digital Twin intelligence management
- Digital Twins modelling for AI for physical augmentation
- Digital Twins for synthetic data generation in Cyber-Physical applications
- Predictive Maintenance in IoT-based Cyber-Physical systems
- Intelligent Digital Twins for optimization use cases (Smart cities, smart buildings, environmental monitoring)
- Digital human replica with AI
- IoT-based Cyber-Physical application with AI in healthcare
- Digital Twins for continual learning scenarios
- Reinforcement Learning in IoT-based Cyber-Physical applications

Besides the aforementioned topics of interest, papers can be of the following types:

- Full research papers(minimum 7 pages)
- Short research papers(4-6 pages)

4. Submissions

The AI4DT&CP 2024 Workshop received 6 submissions, of which 4 were accepted. Articles have been submitted from 5 different countries, i.e., France, Japan, Italy, India, China,

The accepted articles, collected in these Proceedings, have primarily addressed two topics.

- AI-augumented Digital Building Twins: the deployment of AI-augmented Digital twins in the field of smart cities and the management of smart buildings, including knowledge representation.
- AI-augumented Digital Twins for machine control and maintenance.

Across both topics, in the article by Bao et al., entitled: “Towards Digital Twin-based Operation and Maintenance: A Virtual Assistant Framework for Creating Guidelines According to Managers’ Requirements”, the authors introduce a virtual assistant framework that uses Generative Pre-trained Transformers (GPT) to manage the creation and deployment of Digital twins-based procedures for operation and management of the innovative smart university campus at the Zhejiang University for the International School of Medicine. In particular, they addressed several open issues in real-deployment of digital-twin based systems such as: modeling functional and non-geometric data requirements, but also the human-user interaction leveraging the novel large language models.

For the deployment of AI-based Digital twins in smart cities, we can find the article entitled "Digital Twin Orchestration: Framework and Smart City Applications" by Nguyen et al., that

address the challenges introduced by the concurrent interaction among multiple digital twins. In particular, this research work proposes an orchestrator that includes federation, translation, brokering, and synchronization components. Moreover, to demonstrate its efficacy they report the results achieved in a smart environment for hotspot prediction and eco-driving assistance.

Furthermore, in the same topic but addressing another kind of interaction, we find the research work by Reynaud et al., that address accessibility and interpretability of Digital Building Twins leveraging natural language querying. In their work entitled "Knowledge representation for neuro-symbolic digital building twin querying", the authors propose a domain-specific ontology combined with advance AI techniques to enhance communication between users and digital twins for a rapid extraction of information about buildings. In their analysis, the authors also present how knowledge should be represented for effective queries.

Finally, for the second topic, the short paper entitled "On-Edge Implemented Machine-Learning Based Synthetic Flame Detector For Gas Turbine Operation" by Gori et al., brought to the workshop an industrial perspective and experience with a real-time on-edge approach for flame detector in gas turbines. In particular, this research work focuses on the control of MarkVIs device in a closed control loop by leveraging a neural network approach.

The workshop attracted several participants and, according to the participants, led to intriguing discussion about the future developments in this field. Since it enabled fruitful research discussions we can confirm a promising interest for such domain and challenges.

5. Organizing team

Gianfranco Lombardo serves as fixed-term Assistant Professor at the Department of Engineering and Architecture (DIA) of the University of Parma, where he conducts research on Machine Learning, Natural Language Processing, and distributed systems. In 2019, he was a visiting researcher at the Center for Applied Optimization (CAO) at the Herbert Wertheim College of Engineering of the University of Florida (United States). In 2024, he has been a visiting researcher at the LIPN laboratory of the Paris Sorbonne Nord University, where he conducted joint research on “Trustworthy Large Language Models.” In 2021, he co-founded Neuraloo Inc., a technology startup based in Fort Lauderdale (Florida, United States) that commercializes the intelligent analyzer (www.grapho.ai) for financial documents based on Natural Language Processing techniques. Since January 2024 he has served as Associate Editor for the “Operation Research Forum” Journal (Springer). He chaired several international workshops, such as the two editions of AI for Digital Twins and Cyber-physical Applications - AI4DT&CP in conjunction with the International Joint Conference of AI (IJCAI 2023 and 2024, Macau S.A.R and South-Korea). He currently serves as a reviewer for several high-impact journals edited by Elsevier, Springer, and IEEE.

Felix Theusch is PhD researcher at the German Research Center for Artificial Intelligence (DFKI) in the Smart Data and Knowledge Services research department. As project lead in the "DZW"-research project (https://www.dfki.de/en/web/research/projects-and-publications/project/dzw), he conducts research on applications of artificial

intelligence in the field of water supply and develops digital twin applications for the optimization of drinking water systems and wastewater treatment plants based on machine learning methods. The first prototypical applications for energy load management and the optimal use of photovoltaic power have been demonstrated in the municipal water supply of the city of Trier, Germany. He was Technical Chair of the 45th German Conference on Artificial Intelligence https://ki2022.gi.de/ and co-organizer of the AI and Cyber-Physical Process Systems Workshop in 2022.

Marco Picone is Assistant Professor (RTD-B) at the Department of Sciences and Methods for Engineering (DISMI) of the University of Modena and Reggio Emilia. He received the Ph.D. in Information Technology and the M.Sc. (cum Laude) in Computer Engineering from the University of Parma (Italy) and he have also been Postdoctoral Research Associate at the same University from 2012 and 2015. During 2011 he was a visiting student researcher in the NetOS group at the Computer Laboratory, University of Cambridge (UK). His research interests include Distributed Systems, Internet of Things, Edge Computing, Digital Twins, Pervasive and Mobile Computing. He is the author of several scientific publications on international conferences and journals and he published two books titled on Internet of Things and Intelligent Transportation Systems. He has a strong background in middleware and infrastructure for pervasive and interoperable IoT systems and is active in the Digital Twins (DTs) research both from a modeling and design perspective and from the software engineering, development, interoperability, and deployment point of view. He have been directly involved in the organization and participation in international workshops (TwinNets 2022 and 2023 - http://www.twinnets.unipi.it/) and journals special issues (Elsevier Computer Communications - Special issue on "Digital Twins for the Computer-Networks Evolution" - Link) related to the Digital Twin topic with the aim to create a shared community on the topic. Furthermore, he is the designer, developer, and main maintainer of the White Label Digital Twin OpenSource project a Java-based library for the creation of Digital Twins for IoT applications and use cases (https://github.com/wldt).

Diego Reforgiato Recupero is a Full Professor at the Department of Mathematics and Computer Science of the University of Cagliari, Italy. He holds a double bachelor's degree from the University of Catania in computer science and a doctoral degree from the Department of Computer Science of the University of Naples Federico II. He is the co-director of the Semantic Web Laboratory at the University of Cagliari http://swlab.unica.it and founder and director of the Human-Robot Interaction laboratory at the University of Cagliari https://hri.unica.it/ and founder and director of the Artificial Intelligence and Big Data Laboratory at the University of Cagliari https://aibd.unica.it. He is also the coordinator of the new bachelor's degree in Applied Computer Science and Data Analytics at the University of Cagliari and co-founder of six companies, three of which are spin-offs of the University of Maryland, CNR and the University of Cagliari. He is the author of more than 200 scientific papers and has organised more than 15 International workshops. Among those who obtained the highest success in terms of participants and impact, he has previously organised the six editions of the International Workshop on Deep Learning for Knowledge Graphs at the Extended Semantic Web Conference and the International Semantic Web Conference and is

going to organise the forthcoming. Much of the research of Prof. Reforgiato revolves around Deep Learning, Machine Learning and Semantic Web.

Giuseppe Vizzari has organized several workshops and symposia on the topics of agent-based modelling and simulation, in particular, he was co-chair of the ABModSim workshop series (four editions, from 2006 to 2012) in the context of the European Meeting on Cybernetics and Systems Research, and the Advances in Computer Simulation symposium in the context of the ACM Symposium on Applied Computing (2008, 2009 and 2010 editions). He was also workshop co-chair of the 2009 IEEE/WIC/ACM International Joint Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT'09), Milano (Italy), Sept. 15-18, 2009. He is a member of the steering committee of the Agents in Traffic and Transportation (ATT) workshop series, and he was a member of the organization team for the 2014, 2016, 2020, 2022, and 2024 editions.

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