Overview of AI4DT&CP@IJCAI 2023: The First Workshop on AI for Digital Twins and Cyber-Physical Applications*

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Abstract

The 2023 Workshop on AI for Digital Twins and Cyber-Physical Applications (AI4DT&CP 2023) is at its first edition, held in conjunction with IJCAI 2023: the 32nd International Joint Conference on Artificial Intelligence. The workshop aims to bring together experts in the fields of Artificial Intelligence, Digital Twin technology, and Cyber-Physical systems to explore the latest developments and best practices in the use of AI-based digital twins for a wide range of cyber-physical services and applications. We will discuss recent trends and research projects, as well as developments and advances being made in the area of Digital Twins and Artificial Intelligence to address Cyber-physical applications from different perspectives.

Keywords

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

1. Introduction

The availability of easy-to-deploy sensors and the general advances in the Internet of Things (IoT) technology have led to the emergence of new applications that seamlessly blend the physical and digital worlds. Notwithstanding this trend, there are still open issues. A major one, due to the heterogeneity of the several models involved, 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. The idea gained traction among both academic institutions and industry players, revitalizing the Digital Twin technology that enables the creation of virtual replicas of physical objects by mirroring their properties, data, and behaviors [1] and enabling new intelligent and augmented functionalities such as learning, modeling, simulation, and cognitive capabilities. Artificial Intelligence (AI) will transform the

field of Digital Twin technology by enabling the creation of intelligent virtual replicas that may offer smart services and lead to adaptive AI in cyber-physical environments [2]. At the same time, incorporating machine learning models into digital twin systems can be critical 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]. Therefore, we must address these challenges, providing new techniques and methods and exploring the latest developments and best practices in the use of AI-based digital twins for a wide range of 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].

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 [7].

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 [8].

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) [9].

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 [10].

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.

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 three types:

- Full research papers(minimum 7 pages)
- Short research papers(4-6 pages)
- Position papers(2 pages)

4. Submissions

The AI4DT&CP 2023 Workshop received 5 submissions, of which 4 were accepted. Articles have been submitted from 5 different countries, i.e., France, Germany, South Africa, India and Japan.

The accepted articles, collected in these Proceedings, have primarily addressed two topics. The first issue concerns the usage of machine learning techniques to agument Digital Twins; the second issue concerns the application of AI-based Digital Twin in the healthcare sector.

With respect to the first issue, in the article by Theusch et al., entitled: "Towards Machine Learning-based Digital Twins in Cyber-Physical Systems", the authors discuss the open problem related with the systematisation of Machine Learning-based Digital Twins (MLDTs) as well as their methodological development and implementation processes in productive environments. In particular, they introduce a novel process model for the systematic development of MLTDs according to the Machine Learning Operations (MLOps) paradigm which is presented as a tentative instance of a future reference model for MLDTs. Moreover, they leverage such a process model to experiment with an industrial use case related with water resource management.

In the same issue, we can find the article entitled: "Joint Hypergraph Rewiring and Memory-Augmented Forecasting Techniques in Digital Twin Technology", by Sakhinana et al. The authors discuss the open problems in forecasting tasks when Digital Twin are applied to complex sensor networks that require to adapt to non-stationary environments, retain past knowledge and which lack a mechanism to capture the higher-order spatio-temporal dynamics,

and estimate uncertainty in model predictions. They propose a hybrid architecture that enhances the hypergraph representation by incorporating fast adaptation to new patterns and memory-based retrieval of past knowledge. This balance improve the slowly-learned backbone and achieve better performance in adapting to recent changes.

With regard to the second issue related to AI-based Digital Twin for Healthcare, two articles were accepted. The first, entitled: "Neuro-Symbolic Digital Twins for Precision and Predictive Public Health" proposes to enable Precision and Predictive Public Health for population health using Digital Twin, Public Health instruments, knowledge graphs, and AI. In particular, it introduces Neuro-symbolic Digital Twins, which combine semantic reasoning supported by a knowledge graph, deep-learning's predictive power, and a Digital Twins' agility to simulate public health interventions in a virtual environment.

Finally, the article entitled "Re-imagining health and well-being in low resource African settings using an augmented AI system and a 3D digital twin" by Moodley et al. discusses and explores the potential and relevance of recent developments in artificial intelligence and digital twins for health and well-being in low-resource African countries with a specific focus on public health emergency response to disease outbreaks and epidemic control. In particular, the authors propose an initial augmented AI system architecture to illustrate how an AI system can work with a 3D digital twin to address public health goals by leveraging knowledge discovery, continual learning and pragmatic interoperability for decision-making.

The workshop attracted several participants and it has been one of the most participated during the daily session where it was scheduled during IJCAI 2023. Moreover, it enabled fruitful research discussions that confirmed a promising interest for such domain and challenges.

5. Organizing team

Gianfranco Lombardo is Assistant Professor at the Department of Engineering and Architecture (DIA) of the University of Parma. He teaches Mobile Computing and Introduction to Artificial Intelligence and Big Data in the same university. He holds a PhD in Information Technologies. In 2019 he was visiting researcher at the Center for Applied Optimization (CAO) at the Herbert Wertheim College of Engineering of the University of Florida (United States). He is currently an external AI consultant for the European Food and Safety Authority (EFSA) for a European industrial project, and he is the co-founder of an American startup focused on delivering AI products in Finance. He currently serves as a reviewer for several Elsevier, Springer and IEEE journals on topics related to Artificial Intelligence. In 2022 he organized a workshop at the International Conference on Machine Learning, Optimization and Data science (LOD). In 2018 he was in the local organizing team of EVOSTAR 2018 and WIVACE 2018.

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, and 2022 editions.

Acknowledgments

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