LEDGER
ledgerjournal.org

ISSN 2379-5980 (online)
DOI 10.5195/LEDGER.2019.179

NOTE FROM THE EDITORS

Editorial: Proceedings of the First Symposium on Blockchain and Robotics, MIT Media Lab, 5 December 2018

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Abstract. An introductory statement by the editors of the present proceedings, detailing the symposium itself as well as its peer-review process and acceptance rate, a summary of the included papers, and details on the editors themselves.

1. Introduction

Robotic systems are starting to revolutionize many applications (*e.g.*, transportation, logistics, health care) assisted by technological advancements, such as cloud computing, novel hardware design, and novel manufacturing techniques. However, several of the characteristics that make robots ideal for future operations—autonomy, learning, knowledge sharing, *etc.*—can also raise concerns in the evolution of the technology from academic institutions to the public sphere. For instance, controlling the behavior of large teams of robots still presents unique challenges for human operators. In addition, open problems in the fields of data privacy, security, and transparency can become burdens for the future use of robotics technology in highly sensitive scenarios. Therefore, solutions to these problems might be necessary steps towards mainstream adoption.

Blockchain, an emerging technology originated in the digital currency field, demonstrates that by combining peer-to-peer networks with cryptographic algorithms, independent nodes and agents can reach agreements in a transparent manner without the need for a controlling authority. Furthermore, blockchain-based tools such as "smart contracts" are already showing great potential to make robotic operations more secure, autonomous, flexible, and even profitable. They can thereby bridge the gap between purely scientific domains and real-world applications.

On 5 December 2018, the first *Symposium on Blockchain for Robotic Systems* took place at the MIT Media Lab (`http://blockchainrobotics.org/`). This forum aimed to move beyond the classical view of robotic systems and advance our understanding about the possibilities and limitations of combining robots with blockchain technology. During the one-day event insights about the following questions were offered: what blockchain tools are available to increase the

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reliability and transparency of robotic systems? What kind of algorithms are suitable to combine both technologies? Are there new models and methods to connect robots to blockchain-based technology such as "smart contracts"? Are there new business models for robot ventures based on cryptographic algorithms?

An open call for papers attracted twenty manuscripts covering a broad range of topics concerning the proposed synergy and its applications. After two rounds of peer-reviews by a team of international experts, eight papers were invited for oral presentation (40% acceptance rate). Those accepted papers represent a wide spectrum of research under the theme of the event, ranging from blockchain protocols for embedded systems to robotic services for smart cities.

2. Summary of Accepted Papers

The following papers comprise these proceedings:

The first article by Lopes and Alexandre, titled "An Overview of Blockchain Integration with Robotics and Artificial Intelligence," describes the existing work on the blockchain field for robotics and AI applications.[1] In particular, this paper conducts an overview of many different methods and platforms that try to leverage the power of blockchain into robotic systems, improve AI services, or solve problems that are present in the major blockchain platforms.

In Falcone *et al.*, a blockchain-based mapping protocol for distributed robotic systems running on embedded hardware is proposed.[2] This protocol was developed for a robotic system designed to move on lattice structures for space applications. Options, trade-offs, and considerations for implementing blockchain technology on an embedded system with wireless radio communication are explored.

The paper by Venkatapathy *et al.*, titled "Decentralized Context Broker Using Byzantine Fault Tolerant Consensus," presents a decentralized reliable message relaying service (*i.e.*, context broker) for inter-communication between heterogeneous materials handling systems.[3] The paper tests the proposed stack as a proof-of-concept using ROS-based robots in a logistics scenario.

In Tran *et al.*, blockchain technology is combined with swarm robotics systems.[4] The authors describe how robot swarms may experience network partitions either due to navigational and communication challenges or in order to perform certain tasks efficiently. In response to this, the paper proposes a novel protocol, SwarmDAG, that enables the maintenance of a distributed ledger based on the concept of extended virtual synchrony while managing and tolerating network partitions.

In "Robotchain: Using Tezos Technology for Robot Event Management," the authors present a possible solution using blockchain technology that prevents unwanted changes in a robotic action ledger.[5] This work proposes the use of a blockchain ledger to maintain and improve factory productivity. The paper also presents an experimental study of the Tezos blockchain platform in order to explore its capabilities for robotics and automation purposes.

The article by Khawalid *et al.*, titled "Grex: A Decentralized Hive Mind," introduces a simulated UAV search and rescue mission using single board computers as simulated agents.[6] Inter-agent communications were facilitated through Distributed Ledger Technology (DLT) in a completely decentralized network. The paper introduces a new front-end interface to demonstrate the ease with which information can be extracted from the system. Finally, this paper shows the feasibility of DLT in a robotics mission with a practical experiment.

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In "Robotic Services for New Paradigm Smart Cities Based on Decentralized Technologies," different methods of organizing robotic services for "smart cities" using secure encrypted decentralized technologies and market-based approaches are proposed.[7] In this paper, special attention is paid to the integration of technical and economic information into one network of transactions, which allows creating a unified way of interaction between robots: *the robot economy*.

Finally, the paper by Murimi proposes a framework for secure, trustworthy social networking that also creates value for user-generated content by using a blockchain-enhanced framework for social networking.[8] This work explains the application of such a framework for collocated spaces of robots and IoT devices and identifies key challenges that result as a consequence of merging social networking sites and blockchain technology.

3. Conclusions

Collectively, these eight papers illustrate the diverse range of topics currently being investigated in the synergy of robotics and blockchain technology. The papers included in this special issue are representatives of the current research challenges and applications of this combination. To summarize, this special issue shows a clear trend confirmed by the opening literature review paper: blockchain technology has potential to solve several problems of current robotic systems, especially in the distributed robotic systems field, where the complexity of the system grows with the number of robots.[1] Achieving more secure, verifiable, and reliable robot systems seems a pressing issue among the authors.[3–6] It is expected that this trend will grow in the upcoming years. However, there is research already analyzing the impact of this combination in challenging scenarios such as cities,[7] social media,[8] or even outer space.[2] It is expected that these papers can provide researchers with valuable resources and motivations to work on the challenging issues in this new research topic. There is convincing evidence that blockchain technology can play a vital role in assisting robots and cyber-physical systems in becoming accountable, verifiable, and trusted "partners" not only inside factories but in our homes, communities, cities, and even in extraterrestrial operations.

Finally, we would like to thank all authors for their contributions to this special issue. We also extend our thanks to all reviewers for their hard work to ensure the high quality of accepted papers.

Editors' Biographies

Dr. Eduardo Castello is a postdoctoral researcher (Marie Curie Fellow) at the MIT Media Lab. Eduardo is currently working with Prof. Alex ('Sandy') Pentland and Prof. Marco Dorigo in order to explore the combination of swarm robotic systems and blockchain technology to implement new security, behavior, and business models for distributed robotic systems. Eduardo received his B.Sc.(Hons) Intelligent Systems from Portsmouth University (UK) and his M.Eng. and Ph.D. degrees in Robotics Engineering from Osaka University (Japan).

Dr. Hardjono Dr Thomas Hardjono is currently the CTO of Connection Science and Director of the MIT Trust-Data Consortium, located at MIT in Cambridge, MA, USA. Prior to this he was the Executive Director of the MIT Kerberos Consortium, developing the Kerberos protocol to become the most ubiquitously deployed authentication protocol in world today. Over the

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past two decades Thomas he has held various industry technical leadership roles, including Distinguished Engineer at Bay Networks, Principal Scientist at VeriSign PKI, and CTO roles at several start-ups. He has been at the forefront of several industry initiatives around identity, trust and cybersecurity. His areas of interest include cryptography, blockchain survivability, trusted computing, decentralized identity and data privacy. Thomas has authored several dozen technical papers, patents and books covering cryptography, network security, identity and blockchain security.

Professor Alex ('Sandy') Pentland directs the MIT Connection Science and Human Dynamics labs and previously helped create and direct the MIT Media Lab and the Media Lab Asia in India. He is one of the most-cited scientists in the world, and Forbes recently declared him one of the "7 most powerful data scientists in the world" along with Google founders and the Chief Technical Officer of the United States. He has received numerous awards and prizes such as the McKinsey Award from Harvard Business Review, the 40th Anniversary of the Internet from DARPA, and the Brandeis Award for work in privacy.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 751615.

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ISSN 2379-5980 (online)
DOI 10.5195/LEDGER.2019.179

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SSN 2379-5980 (online)
DOI 10.5195/LEDGER.2019.179