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REVIEW ARTICLE

An Overview of Blockchain Integration with Robotics and Artificial Intelligence

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Abstract. Blockchain technology is growing everyday at a fast-passed rhythm and it's possible to integrate it with many systems, namely Robotics with AI services. However, this is still a recent field and there isn't yet a clear understanding of what it could potentially become. In this paper, we conduct an overview of many different methods and platforms that try to leverage the power of blockchain into robotic systems, to improve AI services or to solve problems that are present in the major blockchains, which can lead to the ability of creating robotic systems with increased capabilities and security. We present an overview, discuss the methods and conclude the paper with our view on the future of the integration of these technologies.

KEY WORDS

1. Blockchain. 2. Robotics. 3. Artificial Intelligence. 4. Overview.

1. Introduction

Blockchain technology was first introduced by Satoshi Nakamoto alongside with the crypto-currency Bitcoin.[1] Both have grown in terms of adoption, value and usage,[2,3] but the value of blockchain is not only to hold crypto-currencies but to allow the integration of a huge number of systems over the same platform in a decentralised and secure way. Ethereum,[4] proposed in 2013, introduced new features to the blockchain technology, such as smart-contracts, allowing it to integrate more services and have more value to many industries and academic fields. These projects are still lacking some essential characteristics, like energy efficiency and the speed that a block takes to be validated. With these problems in mind, every year thousands of new ideas and services to work with blockchain technology are proposed, but there isn't a unique solution for all possible applications and that encourages the development of new work. In the robotics field, where integration with blockchain is still low, there aren't many approaches that show how both technologies can overcome challenges. The introduction of blockchain in robotic systems could solve many problems that those systems face. The first problem that it can solve is security, as many of the systems have problems of trust and data integrity, blockchain can provide a reliable peer-to-peer communication with security measures over a trustless network. Another advantage of this integration is the possibility to make distributed decisions since the blockchain can ensure that all participants of a decentralised network share identical views of the

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world. This assurance can allow the system to reach an agreement over the whole network and to have global collaboration between the robots.

In this paper, we give an overview on the current state-of-the-art related to blockchain technology integrated with Robotics and Artificial Intelligence (AI), by studying the major methods that implement services with Robotics, and/or AI. We value the AI aspect of the works because robotics is heavily based on AI systems.

The remainder of this paper is organised as follows: Section 2 explains, reviews and compares the different approaches to the integration of robotics and blockchain. Section 3 presents our ideas and discusses the reviewed methods. Section 4 summarises the main ideas presented throughout the paper.

2. Blockchain and Robotics Overview

In this section we present work that tries to integrate blockchain into robotics.

The work conducted by Bruno Degardin and Luís A. Alexandre (as supervisor),[5] shows how to create a blockchain and use it to store robotic events. This idea allows the creation of smart-contracts that use information acquired on the wild by different robots (possibly from different manufacturers) and have action-triggers based on the contracts that are stored and verified on the blockchain. This can ultimately improve productivity in a factory and reduce the time spent on doing tasks like refilling the screws for a robot that used the blockchain to indicate that he needs more screws to continue is work.

As a follow-up to this work, and now using Tezos' technology,[6] the authors propose the creation of a blockchain for robotic event registration that takes advantage of the improved security provided by the formal verification embedded into Tezos. This on-going work will support smart contracts to run AI code over the blockchain, where these smart-contracts are proved correct (to do exactly what their specification defines). They also plan to adapt the blockchain to support many more events per second than the current specification enables, to allow for the system to deal with a large number of interacting robots.

Aitheon[7] is a platform that adopted a blockchain technology based on the ERC-20 standard. Their goal is to have a complete platform that can reduce the number of time-consuming tasks that developers have to endure, like organising documents. Their solution is a platform with both AI and Robotics that can provide automation for specified business processes. The platform they built has 5 modules. The first, an AI module, tries to retrieve information about frequently performed tasks and takes actions to automate those tasks. The second module, called Digibots, is very similar to the first one, but this module focus on automating programming tasks, like back-end solutions and data-driven problems. The third module, Mechbots, is focused on helping businesses integrate robotic automation to increase efficiency and productivity. The last two modules, Aitheon Specialists and Pilots are human specialists that conclude the tasks that can't be fully automated and also provide robot supervision. In short, Aitheon provides a platform that aims to automate time-consuming tasks by integrating AI and robotics.

Work conducted by E. Castelló Ferrer[8] presents the benefits of combining the blockchain technology with robotics, especially swarm robotics and robotic hardware. The advantages of robotic swarms are how easy it is to scale and the robustness to failure. These advantages come from the fact that members of these swarms are distributed. In the industrial sector we can also

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see how this market is growing and allowing companies to achieve higher productivity, which is the case of AmazonRobotics[9] that has been showcasing its army of robots that cooperatively work to manage their warehouses.[10] Most of the robotic swarms only use local information, this means that a robot only has information about itself and/or robots that are close to it, but the integration of blockchain in these systems can give the robots global information, which can be useful for different applications. The blockchain can also improve the speed of how the system changes the behaviour, since having global information allows the whole system to quickly change behaviour to address specific robot needs. This can also be done by a controller robot that evaluates the system state by using blockchain information and commits to it the changes to be made. These improvements and the global information of the system can lead to higher productivity and easier maintenance.

The authors of RoboChain,[11] which is a conceptualisation of a method to share critical data among robots in a secure way, presented a framework to tackle privacy issues regarding using personal data by robots during a Human-Robot interaction. This method uses MIT OPAL[12] to provide a layer of security and ensure the privacy of the information represented on the data, and with this, the robots can improve Machine Learning (ML) locally with the information they acquired and publish them to the network. The blockchain technology is a part of this framework for transparency and ledger, storing the events that the robot has done during an event and to validate the published models. The authors also propose a consensus mechanism so that every node can vote on which model to accept by taking advantage of the smart-contracts technology within the blockchain.

In a recent work,[13] a methodology to create a coalition of robots, sensors and actuators was proposed. The way this is conducted is by having all the information passing by a knowledge processor and then, insert it into a blockchain. This allows every node of the coalition to have global information and allows the use of smart-contracts to adjust robot actions and reallocate resources. Citing the authors, this systems provides immutable distributed storage that is crucial to negotiate separated tasks among different participants (robots).

3. Discussion

Table 1 contains a short overview of all the methods that were presented in Section 2 and includes some proposals that aim to integrate blockchain with AI and could be used in conjunction with robotics. What we take away from these proposals is that blockchain, robotics and AI are certainly going to disrupt the way we live, since they can bring so much value by themselves, but by joining them together we can compound those benefits. Blockchain can serve as a mechanism for transmitting information between different robots and have action-triggers coded in smart-contracts, improving the efficiency of the robots and their inter-connectivity. Although this will certainly be a fact in the near future, current methods are still in their infancy, mainly because we are going through the explosive growth phase of these technologies, and they are yet to mature. The integration of these technologies could potentially be used in real-time, but for this to happen, the blockchain technology needs to shift to faster consensus mechanisms that allow the validation and insertion of transactions into the blockchain much faster.

From the methods and platforms studied, we conclude that the ones that hold the most promising future are those that integrate many services in a single platform and, at the same time,

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share the code with the open-source community and have reward programs for finding bugs.

Certainly, we will see many robotic systems leveraging the blockchain technology, mainly in industrial and military environments where blockchain can help to automate processes with the help of smart-contracts and enable the systems to have improved security and process traceability. The blockchain introduces a way to trust the data, trust other participants and to conduct internal and external changes by having certified information regarding the whole system. Scenarios where the integration of both technologies are working together to reach a common purpose are easy to imagine. For example, a swarm of "Cop Robots" that patrol the streets greeting people and looking for miss-behaviors. These robots could communicate over the blockchain and have action-triggers with smart-contracts. These could run when they spot a person hurting another, to have the system vote on the best strategy to approach the scene or to call for help. But to achieve this type of behavior, it is necessary that smart-contracts have improved security and are able to interact with information from outside the blockchain (oracles).

It's vital to have platforms that can integrate complementary approaches so that the market reduces from many different separated approaches to a small number of established solutions, or else, define clear interconnection standards to enable multiple solutions to talk to each other.

The marketplaces that are showing up will be crucial to make individual robots able to execute multiple complex tasks without the need for their developers to code all the different necessary solutions. This can and should be integrated with cloud robotics.

4. Conclusions

Blockchain technology is still in its infancy and its possible impact on the global economy is yet to be clearly understood. The integration of services with the blockchain, specially robotics, is still in an early prototype stage. This means that many improvements are conducted in separated blockchains. There aren't yet clear winner technologies and most market participants are not aware of the new technologies and sometimes lack confidence on the robustness of these first proposals. Proposed approaches are abundant, interconnection standards are missing and the integration of those approaches with Industry 4.0 or cloud robotics, e.g., is yet to be achieved.

In this paper, we overviewed many of the current methods and proposals for the blockchain technology that either use robotics or leverage AI services that can improve robotic systems.

As the blockchain technology is maturing it will interact with many other paradigms, such as robotics and AI, to yield improved products and productivity, services and higher living standards for our society.

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Table 1. Short overview of the proposals discussed in the paper. Acronyms used in the table: Blockchain (BC); Smart-Contract (SC); Artificial Intelligence (AI); Machine Learning (ML); Proof-of-Work (PoW); Proof-of-Stake (PoS).

Name	Problem that it's solving	Solution	Consensus	Token	Token compatibility
B. Degardin[5]	Robotic Event Recognition.	Proprietary BC for faster block validation.	PoW	-	-
RobotChain[6]	Integration of robotics and BC, mainly transaction speed and lack of ways to control such a system over a BC.	Usage of Tezos technology for higher security and AI and SCs to improve performance and quality of robotic systems.	-	-	-
Aitheon[7]	Time-consuming tasks that developers endure.	Automation with AI and Robotics.	Multi-blind	AIC	ERC-20
E. C. Ferrer[8]	Problems associated with the integration of BC in Swarm Robotics.	A set of ideas to solve security issues and to improve Robots performance by having more information.	-	-	-
RoboChain[11]	Privacy issues regarding the use of sensitive and protected data.	A robotic swarm interconnected that can use the data to change robots behaviour and that can improve ML algorithms and propagate them throughout a blockchain without compromising the data.	SC based	-	-
N. Teslya and A. Smirnov[13]	Creation of coalitions of intelligent robots.	The use of knowledge processors to insert information acquired by the robots into a blockchain and SCs to manage the system.	-	-	-
SingularityNET [14]	Integration of different AI services so they can work together seamlessly	Marketplace to developers sell their algorithms. An API that automatically call algorithms to solve defined problems.	PoW (binded to Ethereum initially)	AGI	ERC-20
Neuromation[15]	The lack of resources to build AI services and the dispersion of models, datasets and AI services.	A platform to sell datasets, models and AI services. Miners get paid to lend their graphics cards.	PoW (based on Ethereum)	NTK	ERC-20
ATN[16]	Security concerns about selling AI services.	Marketplace based in SCs to provide datasets and AI algorithms in a secure and trustworthy way.	-	ATN	ERC-20, ERC-223, Qtum, RSK
Matrix[17]	Specific languages for SCs, lack of security, slow transaction speed and the inflexibility of the BC.	A NN that automatically converts simple scripts to SCs, by having rules associated with the contracts, by using AI and by delegating the PoW.	PoW and PoS hybrid	MAN	-
J. Chen et al.[18]	Problems associated with consensus on the BC.	A CNN to classify nodes to speed the transactions and lower the energy consumption	AI based	-	-

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