Proceedings of 2019 IEEE
International Conference on Mechatronics and Automation
August 4 - 7, Tianjin, China

Study on Collaborative Algorithm for a Spherical Multi-robot System based on Micro-blockchain

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***Abstract* –Spherical multi-robot system is mainly used to perform field tasks in harsh environments. How to improve the communication distance and task duration, or if the multi-robot system adopts centralized control mode, once the Byzantine general problem arises and the enemy invades the control center, how to make control power of the whole multi-robot system be guaranteed, is the main study of this paper.The Blockchain technology, as a new application of computer science, such as distributed storage, point-to-point transmission, consensus plugin and encryption algorithm, was widely used for financial industry. At the same time, LORA communication technology was also widely used in the field of Internet of Things for its low power consumption, remote transmission distance, and powerful anti-jamming performance and so on. Via the decentralized architecture and LORA communication technology, which can improve flexibility and reliability of the multi-robot system and ensure the control power on battlefield. This paper proposed the Micro-blockchain and collaborative algorithm based on decentralized architecture which can be used for the spherical multi-robot system. On the basis of the theory, an experimental platform was built up and the result shown that it was practicable to set up the Micro-blockchain based on LORA and through this collaborative algorithm, multi-robot system can complete more complex tasks.**

Index Terms - Blockchain. LORA. Decentralization. Multi-robot. Collaborative Algorithm.

I. INTRODUCTION

Spherical robots are mainly used to perform field tasks in a wide range and harsh environments. The multi-robot system has been paid much attention in military applications. But there are two main problems that have not yet been solved. First, single robot requires small size, which limits the battery capacity, but for field tasks, they need to be far away from each other. Hence power consumption should be reduced as much as possible. Secondly, if the multi-robot system adopts centralized control mode, once the Byzantine general problem arises or the enemy invades the control center, then the control power of the whole multi-robot system cannot be guaranteed, which is a very serious problem. Therefore, how to improve the task duration and safety of the multi-robot, while guaranteeing long-distance wireless communication, is the main research of this paper [1].

As the technology behind bitcoin, blockchain has been applied to many industries. Network architecture of multi-robot system based on blockchain can not only avoid the possibility of invasion, solve the Byzantine general problem, but also improve the flexibility and intelligence of the multi-robot system. However, because of the large consumption of computing resources and low efficiency in the application of blockchain in financial industry, and the continuous expansion of distributed data also occupies a lot of storage resources, it is necessary to design a decentralized architecture of blockchain in UAV according to the characteristics of multi-robot system itself, rather than copy it mechanically [2]-[8].

With the development of the Internet of Things industry and the promotion of LORA alliance, more than 400 companies have joined LORA communication technology by the end of May 2017. This fully illustrates the broad prospects of LORA technology. At the same time, its long-distance communication, low-power operation, powerful anti-jamming performance and other characteristics can meet the land communication needs of robots [9]-[18].

On the basis of LORA communication technology, this paper proposed the Micro-blockchain network and collaborative algorithm for spherical multi-robot system. While guaranteeing reliable communication of the multi-robot system, it achieves decentralization, gives the solution to achieve synergy, and finish experiment on the multi-robot system platform. The results show that Micro-blockchain network realized by LORA can operate effectively and reliably in the multi-robot system, which had a good protection on the control power of multi-robot system and increases the cost of intrusion. Finally, we discussed the application prospect of decentralization of multi-robot system.

II. THE PLATFORM OF SPHERICAL MULTI-ROBOT SYSTEM

Our spherical multi-robot platform is shown in Fig. 1. Crawling mode is mainly used on land, and water jet motor is used underwater to realize concealed submergence by injecting. The working environment of robot is generally extreme, including wetlands or rainforests, etc. For multi-robot cooperative tasks, this environment undoubtedly increases the difficulty of communication and control, but the size of robot is limited, and the problem of battery life also needs to be considered. Therefore, increasing wireless communication distance, improving anti-interference ability and reducing power loss of communication are necessary for spherical multi-robot system. They are great practical significance. At the same time, as a military application, if we rely on the central control system too much, there will be great security risks. Once the center is controlled by the enemy, the whole multi-robot will become the biggest threat. Moreover, the individual computing ability of robots is limited, so the total dependence on the center does not consider much for real-time system because of the increase of robots.

In the III part, it mainly talked about the P2P network based on LORA, in the IV part, it mainly talked about the design of Micro-blockchain network, in the V part, it talked about the foundation of decentralization which consisted of the consensus algorithm, in the VI part, it launched the actual experimental verification, and explored in the spherical multi-robot system.

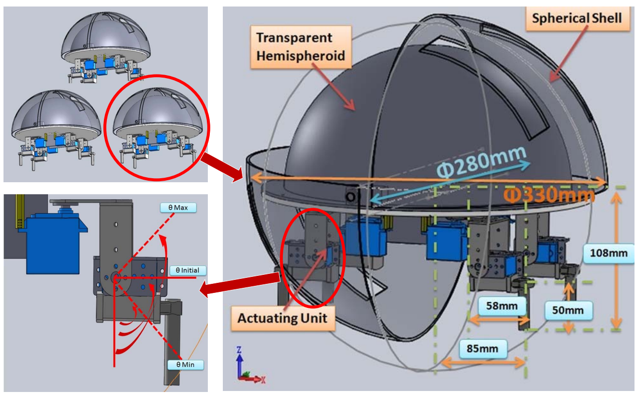

Fig. 1 Structure of spherical robot.

III. The P2P Network Based on LORA

A. LORA communication technology

LORA as a wireless technology based on spread spectrum, which is located in the frequency band below GHz, making it easier to communicate over long distances in a very low power consumption. The receiving sensitivity of LORA in 433 MHz band can reach -148 dBm. Compared with other sub-GHz technologies, the receiving sensitivity of LORA is increased by more than 20 dBm and the coverage in open area can reach more than 15 km. Because of ultra-low power consumption, the battery life is 3 to 5 times longer than other low power WAN technologies under the same conditions.

In low power characteristic of continuous frequency shift keying modulation, it enlarges the communication range and anti-interference. The node with different spread spectrum factors can transmit at the same frequency without interference, which is widely used in military and aerospace communications.

In order to realize the Micro-blockchain, we need to build a point-to-point communication network based on LORA, so that any two nodes in the multi-robot system can achieve two-way communication.

B. P2P network realization

As shown in Fig 2, this is the P2P network architecture composed of n LORA modules. Each module contains SX1278 communication chip and STM32L151 control chip. AT Instruction is used to control the SX1278 chip. The difficulty of constructing P2P network is how to ensure that the data will not be disturbed after losing the synchronization clock, that is, there cannot be multiple nodes broadcasting data at the same time.

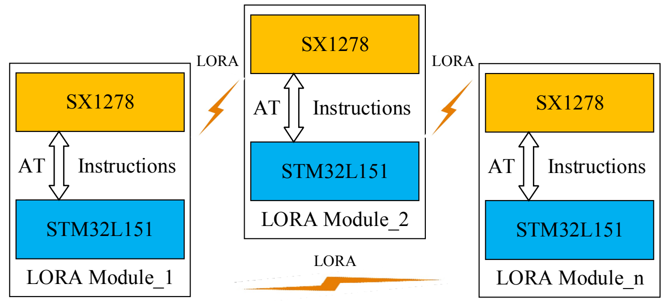

Fig. 2 P2P network architecture design.

In order to solve this problem, my study proposed a heartbeat packet algorithm for regulating multi-node asynchronous communication, by continuously receiving and sending heartbeat packets to make the difference of receiving time of each node basically stable, forcibly switching the status of each node by receiving event interrupt function, so that the sending time of different nodes is staggered and signal interference is avoided. The initial heartbeat packet is realized by genesis block. The specific algorithm for n nodes is as follows:

$$F(S_i) \Rightarrow (n-1) \bullet R_i + \alpha_j \tag{1}$$

In formula (1), function F is expressed as a receiving control function for multi-robot communication, S_i means that a node is in the sending state at time i. Under the control function, n-1 states R_i is generated, which means that after time i, the receiving state of the jth node is delayed by α_j seconds. Here α_j satisfied:

$$\forall \theta, \lambda \in Z \vee \theta \neq \lambda \Rightarrow \alpha_\theta \neq \alpha_\lambda \tag{2}$$

By formula (2) guaranteed (3):

$$\tau(\alpha_j) = S_{i+1}^{j} \tag{3}$$

Finally, the result is expressed that the j node is in broadcast state at the time i+1, which guarantees the different synchronization of S_i and S (i+1; j) by using the difference of receiving data time α_j.

IV. Design and Realization of Micro-Blockchain

The essence of blockchain is to use block chain structure to verify and store data, to reach agreement through node consensus algorithm, and to use cryptography to ensure data transmission and access security.

Among them, blockchain technology such as bitcoin, which serves the financial industry, needs to have sufficient security mechanism protection for sensitive information such as transaction amount and account. Besides the characteristics brought by storage structure, a large part of the computation is focused on security. Therefore, when applying to multi-robot, we should consider the computing capacity, storage and size of volume. It is necessary to simplify the blockchain technology sufficiently, which not only preserves the unique decentralized network architecture, decentralizes decision-making power to each node, but also ensures the security of the multi-robot network and promotes group control to be more reliable.

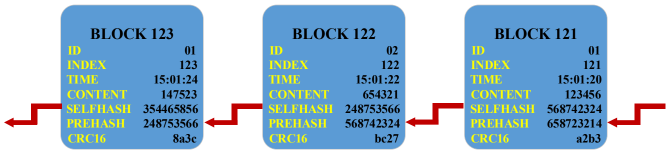

Fig. 3 Architecture Design of Micro-blockchain Network.

The Micro-blockchain network structure proposed in this study is shown in Fig. 3. Each block contains seven parts, which are composed of ID (Robot Number), INDEX (block number), TIME, COTENT (sharing data), SELFHASH (block hash), PREHASH (front block hash), CRC16 (16-bit CRC check), respectively. The chain structure is formed by HASH value and stored on each robot node.

The ID identifies the identity information of each robot node, which is uniquely determined and unchangeable after solidified in the chip memory. INDEX numbering blocks in chronological order can only be incremented by 1. TIME is acquired through GSP module, which is convenient for viewing data information. CONTENT is the specific content part. SELFHASH in each block is the HASH value of the block that the node wants to broadcast. PREHASH is the HASH value in the previous block. The continuity of block generation can be guaranteed by heartbeat packet algorithm. CRC16 adopts the cyclic redundancy check value in MODBUS protocol. Through its verification, the integrity of data package can be judged.

In this study, DJB hash function designed by Professor Daniel J. Bernstein is used. It has fast calculation speed and is widely used in perl, apache, MFC and other applications.

The Micro-blockchain network is specially designed for spherical multi-robot system on land and water. It is different from the environment where the bitcoin blockchain is located. Firstly, in the multi-robot system, each node is controllable and has unique identity information. Compared with the network users, the machine node has higher reliability. Secondly, multi-robot system should pay more attention to real-time, and the PoW mechanism used in Bitcoin takes up a lot of computing resources to solve the decentralization system when the nodes are totally untrustworthy. Therefore, when the application scenarios are different, for multi-robot system, this study abandoned PoW mechanism, but used the authentication of identity information to form a trusted private network.

When the enemy tries to tamper with block information, it needs to crack and generate data in a short time between heartbeat packets, otherwise it will be discarded because the HASH value does not match the original chain. At the same time, due to the decentralized control system, to control more than 51% of the nodes in a short time to complete the above behavior, it needs to invest higher costs [19] [20].

V. The Collaborative Algorithm of Decentralization

This chapter mainly introduces the specific steps and methods of decentralization, starting from the decentralization network architecture design, to the specific consensus algorithm process, and finally achieves the collaborative algorithm of decentralization.

In the spherical multi-robot system, the specific architecture of the Micro-blockchain network constructed by LORA communication technology is shown in Fig 4. It can be seen that the LORA module not only communicates with the controller, but also generates new blocks in the multi-robot network.

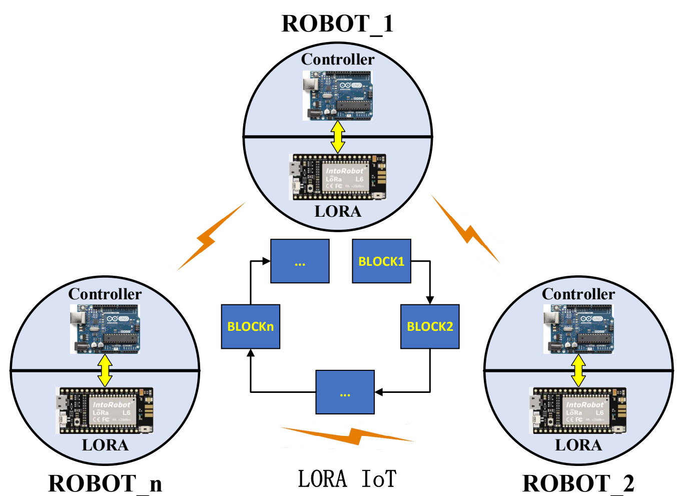

Fig. 4 Decentralized Micro-blockchain Network Based on LORA.

A. *Architecture of Decentralization*

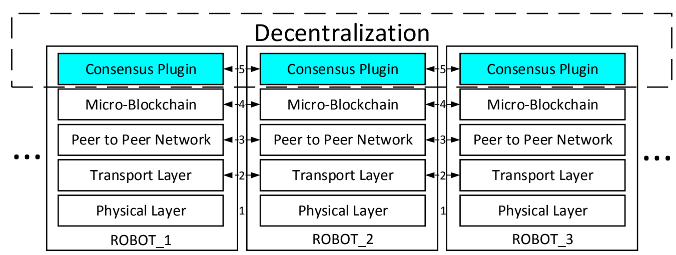

Fig. 5 Architecture of Decentralization.

Distributed system can still use centralized control, and decentralization is achieved on the basis of distributed, through consensus algorithm, to decentralize control to each robot. As shown in Fig 5, for the decentralized multi-robot control system architecture design, it is divided into five layers, with the bottom communication equipment as the first layer, where the communication equipment mainly refers to LORA wireless equipment and underwater acoustic communication equipment. The second layer is the transport layer of LORA network, which realizes bidirectional data flow and CRC16 of data packets. The third layer is the peer-to-peer network layer of P2P communication, which realizes bidirectional communication between multi-robot nodes and controls them through heartbeat protocol. The fourth layer is Micro-blockchain layer, which implements the application of Micro-blockchain in peer-to-peer network on the basis of the third layer. The last layer is the consensus plugin layer, which uses CONTENT in the Micro-blockchain to exchange information. Among the consensus-building schemes, voting and elections are common. In this study, voting is mainly used to reach consensus.

B. Consensus algorithm based on voting mechanism

Consensus plugin runs on the Micro-blockchain network. In this study, robots transmit information to all robots in the target task by voting. Each robot node will vote according to its own situation and select the most appropriate strategy as the group control strategy.

For example, when searching in a certain area, the robot can initiate a voting information about the formation by consensus algorithm, broadcast it to each machine node using Micro-blockchain, and then select the most suitable forward formation according to the actual environment, and broadcast the results to all the robots again, so as to achieve group decentralization control, rather than individual optimization Control [21] [22].

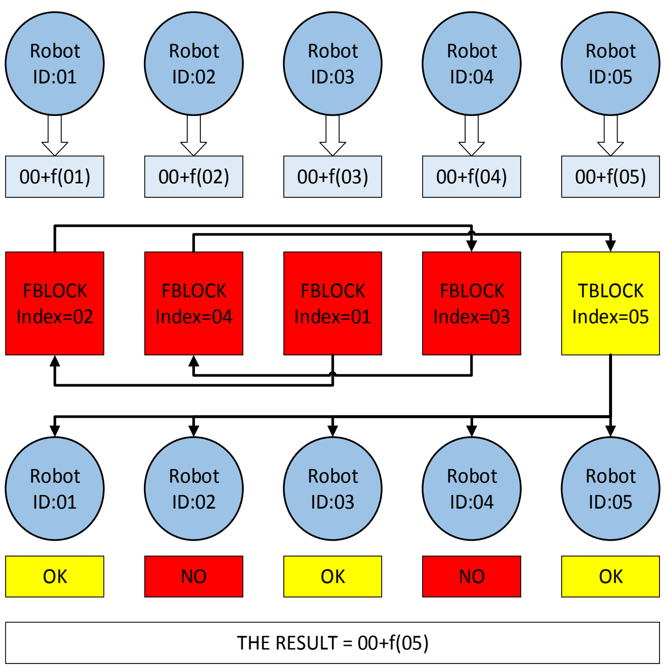

Fig. 6 an Example of Consensus Algorithm.

As shown in Fig 6, the algorithm architecture of consensus among the five robots is shown. Firstly, each robot has a fixed ID. By mapping the ID, the target domain is divided. When a node confirms that the data meets the conditions, the voting mechanism can be triggered. In the first round, the multi-robot system in Fig 5 divides the target domain into five specific values: 00+f (01) to 00+f (05). Among them, the F function is the mapping of ID, dividing the regions according to the rules by different ID values, then judging the voting target according to the sensor data and shared information respectively, and broadcasting the results in the form of Micro-blockchain, in which TBLOCK represents the target domain and passes the test, and FBLOCK represents failure of the test. Index is arranged in chronological order. In Fig 6, block 01 is first generated by the robot with ID 3, while block 05 is the last generated by a robot with ID 5, thus forming the whole Micro-blockchain network [23] [24].

Then TBLOCK will initiate a vote. All robots participate in the test. If 50% or more of the nodes pass, they will act on the target value corresponding to TBLOCK. Otherwise, they will continue to divide the target area and wait for the next round of voting.

The Byzantine problem refers to the fact that there are several generals separated in different places. Loyal generals want to reach an agreement on an order through some kind of agreement, while betraying generals will send wrong messages, thus preventing loyal generals from reaching an agreement on an order. It can be seen from the consensus algorithm architecture that voting can effectively solve the Byzantine node problem [25]-[28].

C. Flow chart of Collaborative Algorithm

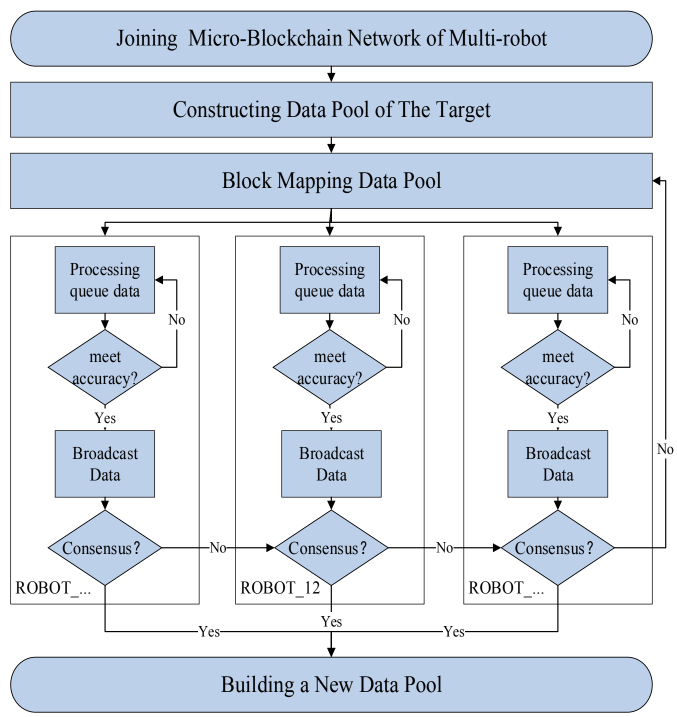

Fig. 7 Flow chart of consensus algorithm.

Fig 7 is the flow chart of collaborative algorithm. Firstly, all robot nodes join the Micro-blockchain network, and then construct the data pool by sensor detection or inter-node communication according to the current task target:

$$\rho(\mathrm{A}) \Rightarrow \Gamma(\alpha_\lambda, \beta_j) = Max(\alpha_\lambda) + \varphi(\beta_j) \quad (4)$$

In formula (4), ρ is a building function for data pools, by mapping the target domain A into MAX maximum function and Φ function, α_λ denotes the value of Γ function after nth segmentation. Φ is the mapping of node β_j. In this study, monotone incremental function is the main ϕ function, where β_j represents the ID value of j node.

Through the above mapping relationship, the target domain is mapped to each node and processed by the Multi-robot system. When a node finds a solution that satisfies its own state, it will vote through consensus algorithm, otherwise it will process the next data of the queue. When all nodes agree on the data of a solution, the current task ends and the data pool for the next task goal begins to be constructed. If the consensus solution is not found for this piece of data, the next piece of data will be partitioned. When there is no consensus in traversing all solution spaces, the solution with the highest number of votes is the public solution.

VI. Experimental Test and Result Analysis

In this study, we take the spherical multi-robot system as the experimental object, construct a LORA-based Micro-blockchain network, and compile a collaborative algorithm. Through experiments, we explore the feasibility of the application of Micro-blockchain network in the multi-robot system.

A. Experimental Platform and Procedures

As shown in Fig 8, the experimental platform consists of two robots and an information collection node for data acquisition.

In this experiment, two robot nodes without chassis lifting action are selected, but the specific actions have been downloaded to the 9th group in the steering control board in advance. One action group can save a series of sequential actions of multiple steering engines. Except for the 9th action group, the other action groups are empty. Then these two nodes and information collection node are placed in the LORA network coverage area, waiting for them to establish the Micro-blockchain network. Finally, the 15 steering gear groups in the steering gear drive plate are taken as the target domain, and the mapping relationship is as follows (5):

$$F(\alpha)=Max\ (\lambda)+\alpha \quad (5)$$

The target domain is segmented, where λ the number of segmentations, F is the mapping of ID value named α, and MAX is the maximum function with the number of segmentations as variables. Through such a simple mapping relationship, the target domain can be completely divided into five times to each node, each time taking three pieces of data, the more nodes, the faster and the traversal speed of the target domain will be. At the same time, the value of MAX is 0 when λ is 0.

B. the data analysis of results.

Through the test of Micro-blockchain network, 11 micro-blocks data were generated in 9 seconds by three nodes. The nodes with ID = 2 and ID = 3 are two normal nodes, and the nodes with ID = 1 is information collection node. Finally, we can see that the multi-robot system has reached an agreement on action group 9. The specific block contents are shown in Table 1 below.

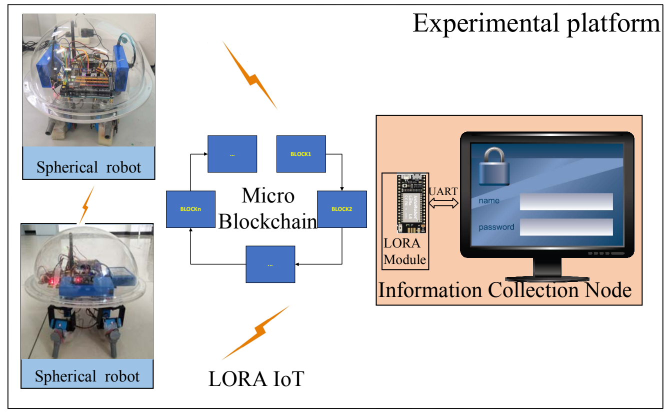

Fig. 8 Experimental Platform.

TABLE I
THE DATA OF MICRO-BLOCKCHAIN

Index	Content	Time	PreHash	SelfHash	CRC	ID
1	000003	20:15:49	3658235353	1054353615	EE89	3
2	000001	20:15:50	1054353615	2861871028	D868	1
3	000002	20:15:51	2861871028	3714167187	E067	2
4	000004	20:15:52	3714167187	2119033628	2AD6	1
5	000006	20:15:53	2119033628	1456280656	1574	3
6	000005	20:15:54	1456280656	3764527739	5098	2
7	000007	20;15;54	3764527739	0600753390	65C0	1
8	000010	20:15:56	0600753390	4239049481	DE27	1
9	100009	20;15:57	4239049481	3680736713	7376	3
10	100009	20;15:57	3680736713	2818041580	D487	2
11	100009	20:15;58	2818041580	1018528592	704D	1

Content is the test result for each group of data. For example, 000003 in the first line is unqualified for action group 3, and 100009 in the ninth line is unqualified for action group 9, which passes the test and votes consensus to other nodes. Therefore, from the 9th, 10th and 11th micro-blocks, we can see that the number of affirmative votes of the 9th action group is 3. Because the number of affirmative votes exceeds 50% of the total number of participating voting nodes, the agreement is reached according to the procedural judgment.

When more and more robotic nodes are available, how to guarantee the stability of the system and the rationality of the smart contract needs to be discussed through formal verification [29].

VII. Conclusions and Future Work

In this paper, based on Micro-blockchain, a collaborative algorithm was proposed. Aiming at the decentralized network architecture and collaborative algorithm of spherical multi-robot system, the transmission layer, P2P communication layer, Micro-Blockchain network layer and consensus plugin layer were gradually completed. Finally, the experiment and validation of the decentralized network were carried out by the spherical multi-robot system. The results showed that collaborative algorithm of spherical multi-robot system based on Micro-Blockchain can be used to achieve action in the multi-robot system application, and met the real-time requirements of control.

This study intends to design more complex tests in the future, and further explore the application of multi-robot system based on consensus plugin. Multi-robot learning algorithm can be designed by consensus plugin. The smart contract can also be used to study a new control method of multi-robot system, which guarantees the freedom of each robot and achieves the overall control for the multi-robot system.

ACKNOWLEDGMENT

This research is supported by National Natural Science Foundation of China (61703305), Key Research Program of the Natural Science Foundation of Tianjin (18JCZDJC38500) and Innovative Cooperation Project of Tianjin Scientific and Technological (18PTZWHZ00090).

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