An Agent-Based Control System for Wireless Sensor and Actuator Networks

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Abstract

This paper aims to propose a novel MIMO control system that is compounded with Distributed Control Systems (DCS) and Centralized Control Systems (CCS). Despite DCS and CCS, which have several drawbacks such as cost and delay, the proposed system is designed to have local and global controllers simultaneously. This MIMO control system has a significant advantage versus the two traditional systems in implementation, computation power reduction, cost decrementing, performance, and the problems that occur in addressing the system connections in DCs for Wireless Sensor Networks and Internet of Things. The proposed system is modeled as a Multi-Agent System (MAS) which is implemented in the osBrain MAS framework in Python.

Keywords: Control Systems, Internet of Things (IoT), Wireless Sensor and Actuator Networks (WSAN), Distributed Control Systems, Centralized Control Systems, MIMO Control System, Multi-Agent Systems

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1. INTRODUCTION

The Internet of Things (IoT) is a communication paradigm, which integrates numerous sensors, actuators, and data to provide valuable services [1]. WSNs networks are utilized for monitoring the physical world [2]. These networks are

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considered as open-loop control systems that only determine the undercover areas of the network. The equipped WSNs with actuators became capable to control and monitor the system [3]. In fact, the WSANs are used in manufacturing, building automation, inventory management in industrial fields [4]. The major computation is done by intelligent actuator nodes that make the network more efficient and optimized, results in the computation power reduction of the ordinary nodes in the network. However, designing the control strategy is an important issue in WSANs. The equipped WSANs are regarded as bidirectional or closed-loop control systems. Actuators enable the system to detect the environments and capture the feedback from sensors, and consequently can correct the operation of the system. Generally, WSANs are divided into two categories including automatic and semi-automatic networks. Automatics use actuators as local decision makers which have higher computation power and power supply than other sensors. They should also be characterized by the larger memory (size) units than ordinary nodes. In contrast, the semi-automatic WSANs use sensors that collect the data from the covered area of the network and transfer them into the actuators; afterward, the actuators send these data to the base station. The gathered data are processed in the base station, then the necessary instructions adopted. The instructions are sent to every actuator node and then each actuator communicates the decisions to the sensors in its cluster. The proposed control algorithms are proportional to the general structure and the type of WSANs. Generally, the distributed control systems and the centralized control systems are proposed for the automatic and semi-automatic WSANs, respectively.

2. DISTRIBUTED CONTROL SYSTEMS

Distributed control systems (DC)[5] are more common than centralized control systems, in which each actuator node considered as a separated local control system[6]. The local control system collects the information from its local sensors as well as the distributed information from other actuators as input information. Therefore, an actuator acts as an independent control system and adopts all the decisions for the whole nodes in own controlling area, and then sends the instructions to the local nodes. In this way, the control system is distributed to the entire network. This control algorithm removes many imperfections of the centralized control system such as the implementation of WSANs in a large area[7]. In the systems, calculations of the control system are divided between the actuator nodes, leading to the reduction of implementation costs. The lack of a global view and general knowledge of the entire network is always a big challenge in the distributed control systems. Although the actuators catch the information from other sections of the network, the data would be unreliable and noisy. The major problem in these systems is the delay in the control algorithm[8]. Each actuator has to make the decision based on the submitted information from other actuators in the different parts of the network. Therefore, each actuator has to wait to receive the required information from other sections. A delay in the whole system would be inevitable if the delay appears in one section. This creates the domino effect and consequently, the delay grows and expands to the whole network. Because of the parallel processing, the distributed control system works slower than the centralized control system. Another issue in these systems is addressing connections between the actuators[8].

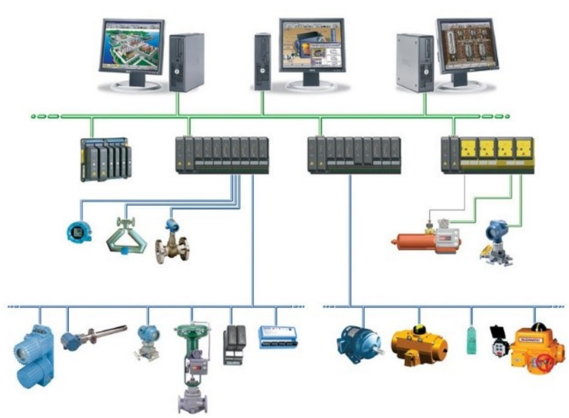

Figure 1: DCS Diagram[2]

3. CENTRALIZED CONTROL SYSTEMS

In centralized control system, the feedback is received from sensors and actuators. After data gathering and processing in the base station, the necessary instructions are adopted based on the feedback. In this algorithm, the base station must have an efficient computation power and an appropriate memory unit. The centralized control base enables the system to have a global view all over the network, leading to creating the equilibrium in the performance of the network. In recent years, The Internet of Things (IoT) technology and the Industrial Internet of Things (IIoT) have become prevalent and practical [9]. Considering the particularities and abilities of WSANs systems, they can be utilized in IoT and IIoT systems. IoT and IIoT systems provide a large number of produced data [10]. For data processing and computing in centralized control systems, Artificial Intelligent networks can be used in the base station. Machine Learning and Deep Learning networks can process the big data obtained from the IoT and IIoT systems. However, some important issues remain problematic in centralized control systems such as performance, unreliability, security, and scalability [11, 12]. Besides, these systems have a disturbance and unreliable noisy wireless communications. The base station must be updated alternatively by receiving information of (about) the system, resulting in a delay in the network.

4. THE PROPOSED CONTROL SYSTEM

Although the distributed control system is more effective than the centralized control system, both systems have some drawbacks including performance and scalability in a very large area. In the proposed system, a new MIMO control algorithm was designed to simultaneously have local and global controllers. This control scheme takes multiple inputs but gives one output[13].

[2]https://www.geeksforgeeks.org/centralized-vs-distributed-version-control-which-one-should-we-choose

[3]https://instrumentationforum.com/t/history-of-dcs-distributed-control-system/9484

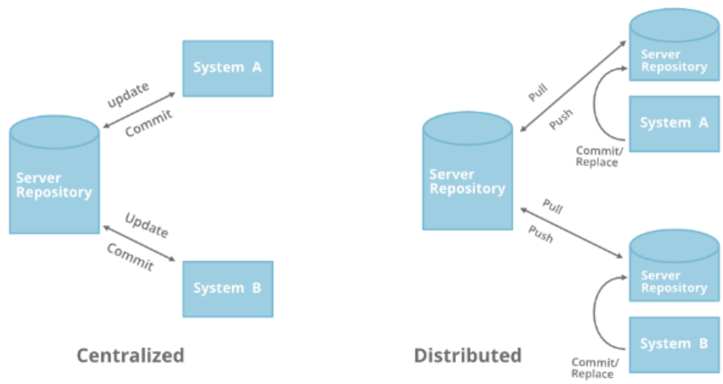

Figure 2: CCS vs DCS Diagram[3]

Goal behavior, steady-state, and required information are considered as inputs of the system. This algorithm is shown in Figure1. The required information obtained from actuators is a feedback of the global control system. The central control base takes the required information as processed data from the actuators in the network. Then the central control base adopts the general instructions in the whole system. With the envisioned future of IoT systems, the role of WSNs would be very important and they may have regarded as the principal constituents of the systems. We suggest multiple inputs for the central control base in a network when some obtained data is processed. These multiple inputs should be connected. The local controllers get the control instructions as input from the central control base. Then the local control systems decide for its local under the area, using feedback from its local sensors. This approach enables the system to keep the control system near to the local sensor and have a global view of the network via the central control base. The central control base takes the required information about each part of the network by the actuators units. In every iteration, the control parameters must be updated in the central control base. This system has advantages over two previous systems at processing big data collected from the sensors. We suggest a Back Propagation algorithm in the Artificial Intelligent network in a local controller to improve and reduce the delay in parallel processing [14]. For the very large area, we suggest that to have multiple central control base. This MIMO control algorithm has a significant advantage versus the two traditional proposed algorithms such as implementation, computation power reduction, cost decrementing, performance, and the problems that occur in addressing the system connections in DCs remove in this algorithm. The mathematical relations are as follows.

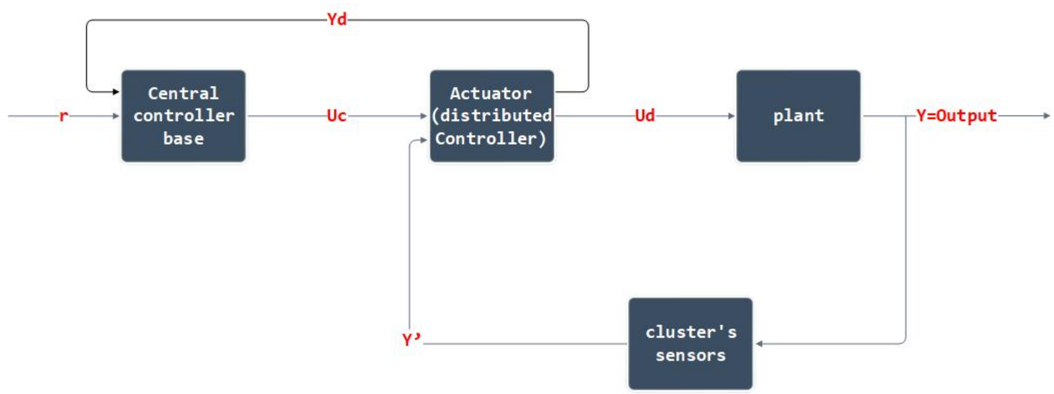

Figure 3: Control flowchart of the proposed Control system

For the Actuator (Distributed Controller) we consider the following equation in which A, B, C, D, V are coefficient and y' is the output of our cluster's sensors, which is equal to y.

$$x_{DC}(K) = A_{DC} \cdot x_{DC}(K-1) + V_2 \cdot B_2 \cdot u_c(K) + V_3 \cdot B_3 \cdot \dot{y}(K) \tag{1}$$

$$u_d(K) = C_2 \cdot x_{DC}(K) + D_2 \cdot u_c(K) + D_3 \cdot \dot{y}(K) \tag{2}$$

$$y_d(K) = C_3 \cdot x_{DC}(K) + D_4 \cdot u_c(K) + D_5 \cdot \dot{y}(K) \tag{3}$$

In the proposed model, the transfer function for the plant is considered as follows. A, B, C, D, V are coefficient and N is the noise we received from the environment.

$$x(K) = A_1 \cdot x(K-1) + V_1 \cdot B_1 \cdot u_d(K) + N \tag{4}$$

$$y(K) = C_1 \cdot y(K-1) + D_1 \cdot x(K) + N \tag{5}$$

Also for the Central Controller, we consider the following equation in which A, B, C, D, V are coefficient, and r is the set point.

$$x_{CC}(K) = A_{CC} \cdot x_{CC}(K-1) + V_4 \cdot B_4 \cdot y_d(K) + V_5 \cdot B_5 \cdot r \tag{6}$$

$$u_C(K) = C_4 \cdot x_{CC}(K) + D_6 \cdot y_d(K) + D_7 \cdot r \tag{7}$$

Finally, we simply consider that the transfer function of the Sensor is equal to 1.

$$\dot{y} = f(y) \cong \dot{y} = y \tag{8}$$

For implementing the control system, we define four agents. The CC agent represents the Central Controller, which has interaction with the AC agent. AC agent is the actuator and is responsible for distributed control of the plant. The Plant Agent characterizes our plant and has interaction with sensors of its cluster, which is represented by CS Agent. We implement the proposed agent-based model in the osBrain environment, which is integrated with the Python programming language that is a great language due to the availability of a huge data analysis ecosystem. The osBrain is a Python-based multi-agent system framework, which allows us to have efficient and asynchronous communication with various communication patterns such as request-reply, push-pull, and publish-subscribe. The communication pattern between CC agent and AC agent is publish-subscribe, which means that the CC agent frequently sends data to the AC agent every second for instance. The rest of the communication patterns are based on a push-pull paradigm, which means that the moment agent receives data; it processes and pushes it to the connected agents. This process brings us asynchronous communication and real-time result.

5. COMPARISON

Due to the development of the IoT systems in recent years, WSNs systems have to handle a big amount of Data. In consequence, The Centralized Control Systems require extremely powerful computing servers to deal with the produced Big Data from the networks. Moreover, the performance of the whole networks depends on the computation power of the servers in their Central Base stations and it increases the threat potential of hacking and costs of implementation including processors in these networks. The processing phase in Centralized Control Systems is not efficient. The whole network has to wait for the Central base to collect all Data and process the information then adopt the instructions. Owning to long processing time and adopting instructions in Centralized Control Systems, they are not appropriate for WSNs, which are sensitive in the term of time delay. These major drawbacks justify that CCS is not considerably effective to process and control the networks especially when control systems have to cover large areas. Unlike the Centralized Control Systems, the Distributed Control Systems necessitate a lower computation power ad reduce the threat potential in networks by processing the collected Data in the actuators. Thanks to the distributed computation servers in the networks, DCS does not necessitate a strong computational center and this leads to lower implementation cost. The Distributed Control Systems are more suitable for covering larger areas in comparison with the Centralized Control Systems. However, despite these significant advantages, Distributed Control Systems endure a determinative disadvantage. The momentous problem with the Distributed Control Systems is that they are not benefited from the global view in the network. One traditional approach is that the actuators are allowed to communicate with each other. However, the network might suffer from the delay when one of the actuators sends its local information and instructions with the delay to the other actuators. In other words, this problem might happen when one of the actuators is hacked or got out of service (died). By using this traditional solution, delay in Distributed Control System will be increased in every iteration upon the domino effect. Another approach is every actuator adopts its required instructions upon its local information. Nevertheless, the lack of the global view causes many problems such as inconsistency among actuators and reduces the potential performance in Distributed Control Systems. This major drawback would bring a remarkable limitation for the implementation of the DCS in large areas. The proposed system attempted to address the mentioned obstacles in

Table 1-Comparison					
	Real-Time	Performance	Scalability	Energy Consumption	Costs
Distributed Control System (DCS)	✗	Modrate	Average Area	Modrate	Modrate
Centralized Control System (CCS)	✗	Low	Small Area	High	High
The Proposed System	✓	High	Large Area	Low	Low

both DCS and CCS methods. As shown in the table below, our works illustrate that the Agent-based Control system for WSNs is more efficient in scalability implementation, computation power and delay reduction, cost decrementing, and performance. Further, our proposed algorithm is inherently real-time and it fixed the delay problem in the network.

6. CONCLUSION

In this paper, we introduced an agent-based MIMO Control System for WSN and IoT systems. The proposed system has been designed to have local and global controllers simultaneously, which enable the system to keep the controller near to the local sensor and have a global view of the network via the central control base. Moreover, we have suggested a Back Propagation algorithm in the Artificial Intelligent network in a local controller to improve and reduce the delay in parallel processing. This MIMO control system has been implemented in osBrain MAS framework in python which has a significant advantage such as computation power reduction, cost decrementing, and high performance.

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