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Further results on cloud control systems

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Abstract This paper is devoted to further investigating the cloud control systems (CCSs). The benefits and challenges of CCSs are provided. Both new research results of ours and some typical work made by other researchers are presented. It is believed that the CCSs can have huge and promising effects due to their potential advantages.

Keywords cloud control systems, cloud computing, cyber-physical systems, networked control systems, big data

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1 Background

With the development of science and technology, combination of informatization and automation is becoming broader and more intensive. Internet of things and cyber-physical systems (CPSs) are typical examples of the combination [1,2]. These systems have attracted much attention from academia, industry as well as the government.

Though the combination of informatization and automation brings about lots of benefits and opportunities, we have to confront many challenges, for example, how to control plants with the emergence of new technologies? With respect to these challenges, some methodological results have been obtained, such as research results of networked control systems (NCSs) and control of complex systems.

Besides the problems induced by the network and complexity, many other challenges also exist in control systems. More and more sensors are used in control systems producing huge data to be processed, and more complex interaction exists between systems and the environment or among system agents, such as in logistics, intelligent transport, carpool management, and cloud robotics and automation. To be more powerful and more intelligent, control systems should consider the capabilities of information exchanging and processing.

However, the traditional conditions of control architecture, onboard computing, storage devices and energy supply, which are often restricted by the plants' size, shape, motion mode or working environment, result in constraints of resources. Information processing and sharing are constrained not only by these factors but also by the communication architecture. These problems can also be found in control of agents

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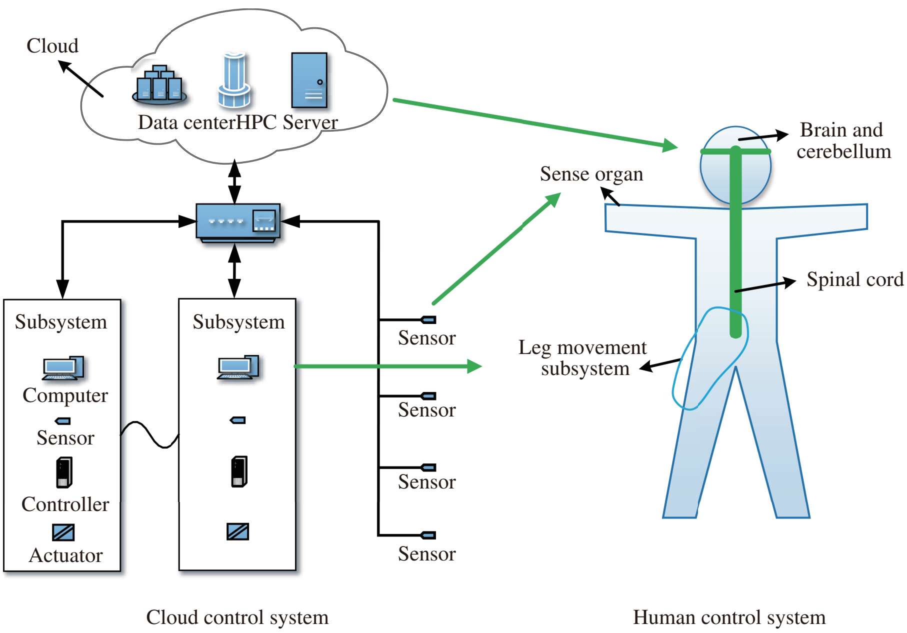

Figure 1 (Color online) Similarities of a CCS and a human control system.

deficient in computational ability, multi-agent systems and complex systems. And the arising big data in some control systems, which is a huge structured or unstructured data set, is difficult to be processed using the traditional database management system.

We can realize that traditional control systems have some deficiencies and new control trends are putting forward serious challenges. One potential solution proposed in this paper is to introduce the cloud architecture to control systems. Cloud computing, which is the development of parallel computing, distributed computing and grid computing, can be seen as a typical part of cloud architecture. It is the commercial realization of these concepts and brings enormous benefits [3]. For example, among the approaches for big data analysis, cloud-based processing techniques are widely used [4]. Moreover, cloud computing is likely to be one of the most popular types of computation providers in the future. The introduction of the cloud architecture to control systems can bring many potential advantages.

2 Definition, benefits and challenges

The concept of CCSs was first proposed in [5] and was investigated further in [6]. A CCS is a novel control system in which the aggregate trend of computational resource is introduced. One 'cloud' can serve for many control systems simultaneously. From the view of architecture, a CCS is mainly a high degree of combination of cloud computing and CPSs. Cloud computing should be adapted to CPSs, and vice versa. It also relates to the knowledge of networked control systems and control of complex systems. CCSs are the results of wide application of cloud computing and the inner development of CPSs.

In its primary form, the cloud is mainly used for calculation of the algorithm, data storage, and processing and analysis of big data. Then CCS develops into a more intelligent system including local subsystem possessing self-control ability and the cloud for computing, scheduling and decision. As depicted in Figure 1, a CCS is architecturally similar with a human control system.

We regard the cloud as the brain and cerebellum, the subsystem as movement subsystem and corresponding spinal cord, large amounts of sensors as the human sense organ, and the communication network as the neural network. Just like knee-jerk reaction is controlled by the spinal cord while complex movements need participation of the brain and cerebellum, CCSs have similar functional processes. About computational mode, the cloud is different from the subsystem just as the brain and cerebellum are different from the spinal cord. Designs of such architecture can make CCSs more powerful and more intelligent.

There are many potential advantages brought by CCSs, such as huge capability of information processing and storage, efficient resource utilization and wide information sharing. The development of CCSs promotes intelligent control and can be a complement to the aggregate trend of computational resource in the information field. In the future, CCSs can provide a platform for developing new algorithms as some software stores for mobile phones do today, which would advocate open competitions for designs and open-source software.

Control performance is sensitive to time and space, while computing mainly focuses on the realization of functions. Thus, a high degree of combination instead of simple applications of cloud computing to CPSs would face many particular problems. Problems existing in cloud computing and CPSs, problems existing in NCSs (such as communication delay, packet dropouts, and multi-rate sampling) and primary problems in control systems (such as real-time control, transient and steady-state performance) do exist in CCSs [7, 8]. Which parts of algorithms are to be processed by the cloud and how to process those parts in the cloud are also critical problems. New and particular problems would arise in CCSs. Studies of theory as well as performance evaluation of CCSs are needed urgently.

3 Research results and applications

In this section, research results of scheduling algorithm, resource reservation management and security which are important problems in CCSs are briefly presented. These results were obtained by the authors' department. Judging from the definition of CCSs, we give some examples which can be seen as applications of CCSs. Trajectory optimization of aircraft is our recent work. Cloud robotics are attracting more and more attention. Analyzing EEG using cloud computing is done by other researchers. The motivations of the three applications are in accordance with the motivations of CCSs as showed in Section 2.

3.1 Scheduling algorithm

The advent of cloud computing provides a new service delivery mode in which users typically 'pay as you go'. Users have quality of service (QoS) considerations of workflow, such as deadline, cost, security and so on, whereas service providers must take profits into account. Thus, improvement and optimization of workflow managements are meaningful. In [9], a workflow scheduling algorithm called control structure reduction algorithm was proposed.

3.2 Resource reservation management

Most control systems must process in real time. As more and more applications are deployed on the cloud platform, how to ensure that CCSs would function well for real-time tasks? In [10], a resource reservation management was proposed to guarantee that resources are available at the needed execution time within the QoS constraints.

3.3 Security

Along with the advantages brought by CCSs, big challenges also exist. Control systems are connected to the Internet, which produces opportunities of Internet attacks. As control systems become bridges of the virtual world of information and the physical world, the security is important. Security of control systems and normal IT infrastructure are different. In control systems, the availability of data is vital as it clearly affects the real-time performance. However, in normal IT infrastructure, the confidentiality of data is comparatively more important.

Typical attacks to availability of data include attacks of denial of service. Besides these attacks, there are deception attacks and replay attacks towards control data and data of sensors. In CCSs, attacks to network layer with purpose or strategy as well as disturbances and uncertainties in physical layer should be considered, which raises the difficulty. Therefore, control, communication and computation should be taken into account comprehensively. Modern NCSs require better adaptation and resilience of control method and control structure to adapt to complex environment. The distributed and redundant features of CCSs are suitable for the requirements of security of modern control systems.

3.4 Applications

3.4.1 *Trajectory optimization of aircraft*

As one of the critical technologies of aircraft reentry control, reentry trajectory optimization is important. It is often formulated to be a nonlinear multi-constraint optimal control problem which is difficult to be solved analytically. Numerical techniques are frequently used to approximate the continuous solutions [11]. However, limited computing power of aircraft cannot ensure real-time trajectory optimization. So we design a cloud architecture to reduce the computational time, in which most computations are performed in the cloud.

Gauss pseudospectral method (GPM) is used to solve optimal control problems. Considering GPM may not obtain the global optimal solutions because of intrinsic limitations, we use genetic algorithm and ant colony algorithm, whose global convergence effects are better, as complements to GPM [12]. Simulation results showed that the method can perform trajectory optimization tasks in distributed computational environment which can be used in practical applications to reduce computational time.

3.4.2 *Cloud robotics*

Google's James Kuffner coined the term 'Cloud Robotics' in 2010. Cloud robotics and automation systems can be broadly defined as any robot or automation system that relies on data or code from a network to support its operation, i.e., not all sensors, computation, and memory are integrated into a single standalone system [13]. By using wireless networking, big data, cloud computing, statistical machine learning, open-source, and other shared resources, the cloud has potential to enable a new generation of robots and automation systems in the application areas including autonomous mobile robots, cloud medical robots, service robots, and industrial robots. There are many application cases, such as RoboEarth, KnowRob, RoboBrain, and 'Ke Jia' intelligent service robot.

3.4.3 *Analyzing EEG using cloud computing*

Ericson et al. trained the neural network and classified the EEG signals from multiple users to infer their intended actions in a distributed environment, which allowed a user to initiate actions such as keyboard input or control the motion of their wheelchair [14]. The results demonstrated the suitability for classifying multiple EEG streams in real-time.

4 Future prospects

CCSs have some potential advantages and would play an important role in many areas. Intelligent transportation systems and smart homes can benefit from the development of CCSs. Also, there will be more and more cloud robots. Robot app stores will be popular in the future as app stores in mobile phone area today.

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