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Guest Editorial
Networked Control Systems: Theories and Applications

Networked Control Systems (NCS)

Computer communication network, particularly the Internet, is playing a role of ever-increasing importance in science, technology and our daily life. Communication network technologies are not only offering people a new way of living and working, but also bringing control engineers a 'revolutionary control world'. It is because communication network technologies offer an unprecedented interconnection capability and ways of distributed collaborative work, and have a great potential to bring these advantages to the high-level control of plants. Introducing a communication network into a control system is not a new concept in automation. Tele-operation might be the first control system involved with computer communication and has many applications in space and hazardous environment handling. Tele-operation is the performance of remote work. The local site and remote site are geographically separated and linked through a communication channel. The modern communication channel is a computer communication network. Introducing a communication network as a component into a control loop, i.e. closing control loops over a communication network, has generated a new type of control systems namely networked control system (NCS). Formally, a control system communicating with sensors and actuators over a communication network is called a NCS. Commercial distributed control systems such as Honeywell TDC-3000 series belong to this category with a local communication network involved.

In the traditional control system an operator gives a desired input to the controller. The controller outputs the control signal to the actuator based on the difference between the desired input and the measured output. The actuator passes the control action and influence on the plant. The measured output is fed back to the controller through the sensor. There are three ways to introduce a communication network into the traditional control system. The straightforward way is to allow the operator located in the remote site to send control commands (desired input) to the controller located in the local site with the plant through the communication network. In order to monitor both the performance of the controller and the situation of the plant the measured output and/or some visual information are required to feedback to the operator at the remote site. Because the communication network is excluded from the closed loop and the controller is located at the same location with the plant the network transmission delay will not affect the performance of the control system. In some cases such as virtual control laboratory and remotely design of controller, it is necessary to locate the controller in the remote site, which is connected with the actuator and the sensor through the communication network. The communication network has become part of the control system in this case. The network transmission delay is introduced in both the actuator and sensor communication channels. The most practical NCS adopt a bilateral control structure, i.e. one controller located in the plant site, another in the operator site, and linked through the communication network. For example, based on this control structure, robotic tele-operation uses the controller in the plant site to control the slave device, and uses the one in the operator site to control the master device. Another example is the advance control for manufacturing processes. Usually the controller in the plant site is responsible for the regulation of the normal situation. Once the performance of the controller is degraded due to the disturbance from the environment or the change of the production situation, the controller in the operator site is put in use for tuning the parameters and/or changing the desired input for the controller in the plant site.

Internet-based Control Systems (ICS)

In the last decade, the most successful network developed has been the Internet. It has made a significant impact on society through its use as a communication and data transfer mechanism. Many systems are being created all over the world to implement Internet applications. Most of them are being focused on tele-robotic systems. The creation of virtual laboratories over the Internet for education purpose is also one of the areas that are being currently developed. Normally we call the NCS involved with the Internet as Internet-based Control Systems (ICS). Research on ICS is focusing on guiding the design process, dealing with Internet latency, and assuring the safety and security. ICS creates a new window of opportunity for control engineers, allowing them to

- Monitor the condition of machinery through the Internet;
- Remotely control machine;
- Collaborate with skilled operators situated in geographically diverse location;
- Integrate client needs in production lines;

- Manufacture on demand through the Internet;
- Provide students in distance learning with experimental environments through real and virtual laboratories.

In addition, customers from every point in the Internet can directly monitor the conditions of manufacturing for making orders and building their confidence on the enterprise. It will bring the enterprise a huge economic benefit especially in the current strong competition.

Challenges of NCS and ICS

There are a number of challenges, which NCS and ICS must face. Three major challenges are network latency, safety and security, and multiple user access. The data transmission latency is the main difference between NCS/ICS and other tele-operation. Most tele-operating systems are based on private media, by which the transmission delay can be well modelled. The Internet in contrast is a public and shared resource in which various end users transmit data via the network simultaneously. The route for transmission between two end points in a wide area is not fixed for different trails and the traffic jam may be caused when too many users traverse the same route simultaneously. The transmission latency of any public network is difficult to model and predict.

Although introducing a public communication network such as the Internet into control systems has yielded benefits through the open architecture, there are various risks, which result from the application of network technologies. One typical risk is an operational difficulties caused by attacking cyber terrorists. The Internet is always opened to hackers because of the open architecture. The hackers will try to cause failures by triggering from the Internet through the open architectures. Therefore the scope of the ICS controlled plant safety cannot be limited within plant sites, because there is a possibility that the local control system would be accessed or falsified by outsiders through the Internet. On the other hand, authorized remote users may cause failures in the plant as well due to the Internet environment constraints.

Compared with the local control system, the special features of NCS and ICS are multiple users and the uncertainty about who the users are, how many users there are, and where they are. In NCS and ICS, the operators cannot see each other, or may never have met. It is likely that multi-users may try to concurrently control a particular parameter. If authorized users have the same opportunity to fully control the whole plant some problems could arise. Some mechanism is required to solve control conflict problems between multiple users, and coordinate their operations.

Although the notion of NCS and ICS is still in its infancy to the academic control community, it is not new to industry. It has been using in manufacturing plants, aircraft, automobiles, health care, disaster rescue, etc. A number of automation & instrument companies have made their hardware and/or software products Internet enabled. For example, the latest version of the LabView produced by the National Instrument (NI) has the function of the remote control over the Internet. Intuitive Technology Corp. provided web@aGlance for feeding real-time data to an Internet enabled Java graphics console. WinCC from SIEMENS is able to link local control systems with the Internet. Sun Microsystems, Cyberonix, Foxboro, Valmet, Emerson and Holywell have made their products Internet enabled as well.

However, if you ask the industry how to choose the NCS and ICS architecture, how to overcome the data transmission time delay and data loss, and how to ensure the safety and security for the Internet enabled control systems, the answer you received might be not so convincing. The reason is simple. These fundamental issues in the design of NCS and ICS are currently under investigation in the academic control community and there are not available convincing answers to them although they have captured the interest of many researchers worldwide.

Contents of the Special Issue

In this issue we return to the submissions in response to our open call for papers. We received 12 articles for this call. All of them were reviewed by experts in this field, and four of them have been selected for publication here, which span different topics in NCS and address some of the fundamental issues presented above. One of them is recommended for publication in an ordinary issue.

The first paper, by X. He et al., "Networked fault detection with random communication delays and packet Losses" deals with the fault detection problem for a class of discrete-time networked systems with multiple state delays and unknown input. Two kinds of incomplete measurements, namely, measurements with random communication delays and measurements with stochastic packet losses, are simultaneously. Attention is focused on the design of a fault detection filter. A sufficient condition for the existence of the desired fault detection filter is given.

The second article, by G.P. Liu et al., "Networked predictive control of systems with random delay in signal transmission channels" investigates the design and stability of NCS with random delay in signal transmission channels. A networked predictive control strategy is proposed for discrete networked systems. The key parts of the control strategy are the control prediction generator that provides a set of future control predictions and the network delay compensator that compensates for the network transmission delay.

The third article, by Y. Yang et al., "Design of a networked control system with random transmission delay and uncertain process parameters" discusses the compensation of the transmission delay in a NCS with a state feedback, which possesses a randomly varying transmission delay and uncertain process parameters. The compensation is implemented by using a buffer in the actuator node and a state estimator in the controller node. A sufficient condition for the stability of the NCS under the designed compensation is proposed as well.

Finally, the article, by M. Deng and A. Inoue, "Network based nonlinear control for an aluminium plat thermal process" discusses an application of network based nonlinear control in an industrial process. This is done by using operator based robust right coprime factorisation approach and Bezout identify to guarantee robust stable network control system, as well as an operator based tracking controller to ensure the controlled process output tracking the desired reference input.

In summary, NCS and ICS are realistic and have a great potential to bring a huge economic benefit to industry. It can be efficient, safe and secure if a control structure, a control strategy, and safety and security measures are properly chosen in the design of control systems. There exist exciting prospects for innovation and impact in this area. May this brief foretaste encourage you to read further and contribute to the research and application of NCS and ICS.

Finally, as the guest editors of the special issue, we would like to thanks all the authors who submitted papers to this special issue for their valuable contribution. Most importantly, we would like to express our appreciation to all reviewers who spent their precious time to complete the paper review process within a limited time. Without their effort, we would not be able to produce such a quality issue. Last, but not least, we would like to thank the Editor-in-Chief of International Journal of Systems Science, Professor Peter Fleming, for his full support and encouragement he has given us in the preparation of the special issue.

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