Network Control Systems: Performance Analysis and Design

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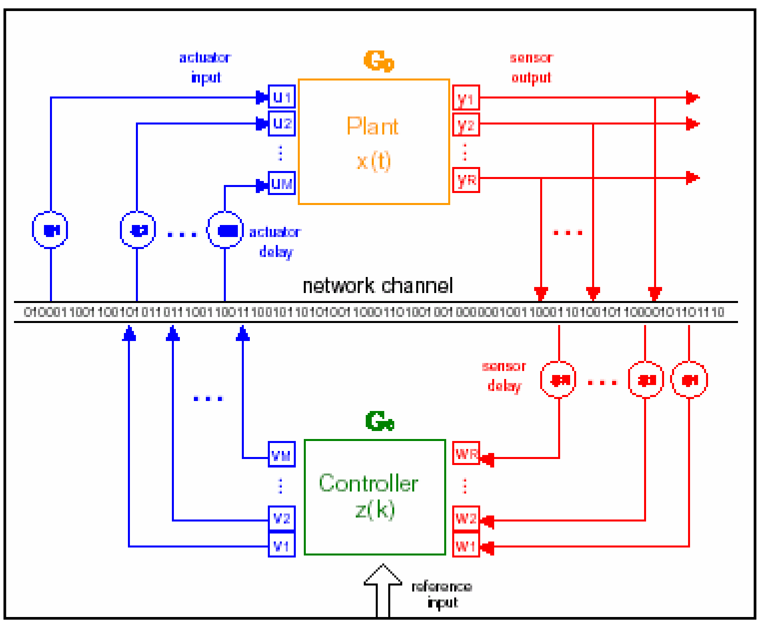
Introduction

Networked Control Systems (NCSs) are one type of distributed control systems where sensors, actuators, and controllers are interconnected by communication networks. The study of NCSs is an interdisciplinary research area, combining both network and control theory. A major trend in modern industrial and commercial systems is to integrate computing, communication, and control into different levels of machine/factory operations. The traditional communication architecture for control systems is point-to-point, that is, a wire connects the central control computer with each sensor or actuator point. This change to common-bus introduces different forms of time delay uncertainty between sensors, actuators, and controllers. Most NCS research has focused on two areas: communication protocols and controller design.



Networked Control System

Networked Control Systems

The research methodology of NCSs mainly focuses on the study of the following three components: network systems, networked devices, and control systems.

Control networks

There are three key components of control networks analysis are network architecture, network protocols, and network performance analysis. Network architecture allows devices such as sensors, actuators, and controllers to be interconnected together, using less wiring, and requiring less maintenance than a point-to-point architecture. It also makes it possible to distribute processing functions and computing loads into several small units. The performance metrics of network systems that impact control system requirements include access delay, transmission time, response time, message delay, message collisions, message throughput, packet size, network utilization, and determinism boundaries.

Network architecture

The Network architecture in a modern manufacturing system has three different levels, namely, the Information/System (IS) network, the Discrete-Event/Cell (DEC) network, and the Continuous-Variable/Device (CVD) network.

Network protocols

The three types of control networks commonly implemented in industry are Ethernet-based, token-passing, and CAN-based networks. Ethernet (IEEE 802.3) is a CSMA/CD1 network protocol.

Performance comparison of control networks

The goal of a control network is to provide a guaranteed quality of service such as deterministic time delays and maximum throughput for real-time control applications. There are now a large number of networks available for applications at the information level as well as at the device level. These networks target various types of industrial automation and processing applications and are distinguished through static parameters such as data rate, message size, medium length, supported topology, number of nodes, and dynamic parameters such as MAC mechanism, message connection type, interoperability, and interchangeability.

Networked devices

Networked devices include smart sensors, smart actuators and networked controllers. Smart sensors and actuators have three major features: data acquisition, intelligence and communication ability.

Control systems

The goal of NCS design is to guarantee the stability and the performance of applied control systems, i.e., meets the control system specifications. These specifications include phase margin, gain margin, overshoot, steady state error, and tracking error. Simply speaking, the limited network bandwidth introduces unavoidable time delays in a control system. These time delays could potentially degrade a system's performance and possibly cause system instability.

Modern control applications

Nowadays, various industrial plants cover large areas and have sophisticated control systems. These systems control a great number of devices and correlate them by means of computationally intense algorithms. Having these algorithms in a single centralized processor or controller can induce several problems due to the hardware and software constraints. These include single point of failure, poor reliability, poor performance, and inability to support advanced distributed control scheme.
The solution currently adopted to address modern control problems is to distribute the processing functions of these systems over several physical nodes, each dedicated to a part of the control process and to a group of sensors/actuators. These nodes cooperate with each other, communicating through a shared physical channel which generally has a bus topology.

Networked control systems design considerations

When discussing the interaction of network and control parameters, most research focused on scheduling message and sampling time assignment for different control systems interconnected by one common-bus network, the sampling period of each control loop was determined by the limitation of maximum loop delays and the availability of network bandwidth, so as to meet both the control stability condition and the network schedulability condition. The multi-hop topology, on the other hand, provided a quick solution for maintaining the timing requirements. However, additional hardware and software were needed to implement the message transmission between hops, increasing the system cost.

Time-delay systems

The modeling and control of NCSs are based on the analysis framework in time-delay systems which have been studied for several decades. In general, delays occur in the transmission of signals or materials between different subsystems. Large-scale systems such as communication systems, manufacturing systems, transportation systems, power systems, and tele-operation systems are typical examples of time-delay systems. There have been two approaches used to analyze the stability of time-delay systems: classical (frequency domain) and functional (time domain) approaches. Another important resource of time delay is the computation-time delay of a microprocessor or controller computer. The computation time is the time taken to execute programs that implement control algorithms at controller nodes or process data coding at sensor/actuator nodes.

Modeling and control of networked control systems

Research in NCSs is different from that in traditional time-delay systems where time delays are assumed constant or bounded. Because of the variability of network-induced time delays, the NCSs may be time-varying systems, making analysis and design more challenging. Recently research on the analysis and modeling of NCSs has been conducted using continuous-time and discrete-time models. It is more natural to analyze an NCS from the discrete-time point of view since in a typical NCS operation, physical signals (from sensors or to actuators) are sampled and then transmitted on the network medium after a short delay. For discrete-time models, most researchers assume that the network is synchronized and the sampling rates of sensors, controllers, and actuators are the same. In practical applications, however, sensor-controller and controller-actuator delays are different and time-varying at different networked devices due to the network transmission mechanism. An NCS should be modeled based on the characterization of network-induced delays and the consideration of network and control parameters. Furthermore, controller should be designed based on the NCS model and take into account the delay information.

Conclusion

Due to the need for network systems in modern control applications, the main research issues in NCSs are the performance evaluation of different control networks, network and control design considerations, and modeling and control of NCSs. However, previous studies only focused on the timing parameters and performance in either network or control systems. Since an NCS has an integral link between network and control parameters, the overall stability and performance of an NCS should be analyzed based on the characteristics of timing parameters in both systems. Therefore, in this research, we propose a systematic methodology to analyze, design, model, and control an NCS.

References

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