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An Overview of Networked Control Systems

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Abstract: The main problems, which are common in networked control systems (NCSs), for instance, network induced delay, packet dropout, network scheduling and network security of NCSs are introduced in this paper. Then, the research methods and the current status about NCSs are introduced based on the common problems of NCSs in recent years. Finally, the problems that needed to be further studied in NCSs and future research directions of NCSs are discussed.

Keywords: Networked Control Systems, Network Induced Delay, Packet Dropout, Network Scheduling.

1. Introduction

With the rapid development of electronic and network technologies, the network technology has been widely used in traditional control systems [1, 2]. In this way, the controllers, actuators and sensors are connected through the network to form a control loop, which is called networked control systems (NCSs). Compared to traditional point-to-point control systems with poor anti-jamming ability and complicated wiring [1], the NCSs are supposed to have higher system agility, lower-cost and easy to expand [2]. As a result of these advantages, the NCSs have been widely used in industry [3], tele-surgery [4], intelligent vehicles [5], and unmanned aerial vehicles [6, 7]. Since the network, which is limited by bandwidth, channel capacity and so on, is one of the most important components of NCSs, so we have to consider the impact that this ‘communication bond’ may bring to the control system. Consequently, the problems in NCSs and the research of NCSs in recent years will be discussed in the paper. The structure of traditional distributed control system shows in Fig.1. Fig.2 illustrates the structure of NCS.

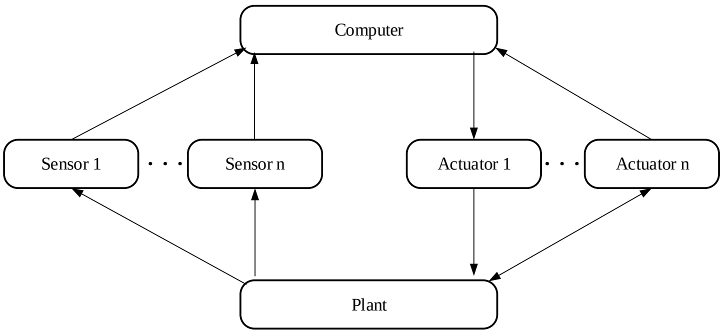

Fig. 1 Structure of Distributed Control System

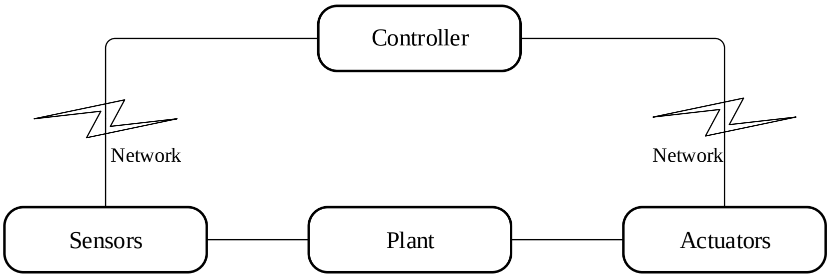

Fig. 2. The Structure of NCS

2. Problems in NCSs

2.1 Network Induced Delay

In the NCSs multiple nodes share the only communication line, the network induced delay will inevitably happen when there is a data transmission between controller, sensors and actuators because of the uncertainties and unreliability of the network [8]. What makes things worse is that once the network induced delay is produced, the controller will not able to get the data from sensors in time and as well as the data transmission between controller and actuators. The network delay will degrade the control performance of NCSs and may even lead to system instability [9, 10]. Due to the different network protocols and hardware devices used, as well as the load conditions of the network, the resulting delays are different, which may be bounded, fixed or random. There are mainly two ways to reduce the impact of network induced delay on the system, the first of which is design a communication protocol to minimize the delay [11]. And the second way is to send the data with a time stamp, which means the cost of the delay can be estimated by the receiver [2].

2.2 Packet Dropout

When the data is transmitted between controllers, actuators and sensors, packet dropout will occur because of the band-width limitation and excessive packet size [12]. However, the packet dropout may usually happen under the following two conditions. One is too many packets are transmitted in the same time causing the collisions between packets. And the other is if the receiver does not receive the packet within a certain time, the packet will be discarded in order to ensure the validity of the transmitted data. Since the real-time requirements in NCSs, there can be only a certain value of packet dropouts, otherwise the system will be unstable [13].

2.3 Network Security of NCSs

More and more network technologies are applied to NCSs, as a result of which the NCSs becomes such open systems. The NCSs depend on the network to transmit the important data, which means many unforeseen weaknesses in the control system will be lead to NCSs [27]. Consequently, these uncertainties will easily be used by the adversary to launch attacks on vulnerable systems, which will reduce the performance of NCSs or even make the NCSs unstable systems [28][29]. Hence the network security of NCSs becomes so vital a problem in order to ensure the stability of NCSs.

2.4 Network Scheduling

There are many factors that determine system performance in NCSs, such as control algorithms and scheduling. The main idea of network scheduling is to take the current situation of the system into consideration in order to make the nodes in the system to send packets at the right time [14][15]. For NCSs the more data sampled and the more convincing the conclusion that made through the sampled data will be. But in fact a large number of data samples will increase the network load of the system, which requires scheduling to coordinate the relationship between control and network. As a consequence, more attention should be paid to network scheduling.

3. The State of NCSs Research

Problems about communication delay are shown in [17], [18], [19]. In [17], the event trigger mechanism is used to study the output-based predictive control of the network control system with communication delay. Then an output-based ETM is introduced and the Luhenberg observer is used to estimate the system state. Then a model-based networked predictive control method is proposed to actively deal with the system delay and stabilize the system. In [18], to overcome the communication delay, congestion and network utilization, a discrete high-order sliding mode based on event-triggered and delay compensation is proposed. And Thiran’s approximation is used to construct an event- triggered sliding variable and a discrete-time super-twisting algorithm is used to update the control actions. Moreover, the Lyapunov method is used to guarantee the finite convergence of the system state within the sliding zone. To degrade the uncertainly of the communication and controlled object subsystem, a new condition for uncertain NCSs to meet $H\infty$ performance requirements is established in [19]. And using linear matrix inequalities, sufficient conditions for the design of robust $H\infty$ output feedback controller are given. Finally, an example is used to verify the effectiveness of the proposed controller.

In [20], [21], are the researchers about packet dropout. The network optimal output tracking control and stability problem control system and data packet loss through output feedback control are studied in [20]. Using the Riccati equation, a principle of maximizing the optimal output feedback tracking controller is proposed. And a necessary and sufficient condition for system stability and optimal output feedback are given under the situation of infinite horizon. In [21], an analyzation about the optimal performance of the multiple input multiple output NCSs is given. And a new explicit expression for the optimal performance is proposed, using the optimal parameterization of the two-degree-of freedom controller and the H2 norm method is used to obtain the optimal performance. The conclusion is drawn that the position and direction of the non-minimum phase zero and unstable pole of a given object are related to the optimal tracking error. Moreover, the optimal tracking error depends on correction factors such as channel noise, quantization noise, coding and encoding, time delay and packet loss probability.

In [16], [22], [23] are researches about the NCSs under network attacks. Guo L et al. [16] studies the security control problems of a class of discrete linear time-invariant systems under noises and DoS attacks. A random model that obeys the Bernoulli distribution is used to describe DoS attacks and some sufficient conditions for the stability of the input state of the system under the action of noise are given. In [22], a new attack and defense strategy is proposed in the face of a stealthy attack, named zero- dynamic attack (ZDA). In [23], this paper studies the triggering control of switching events of NCSs under DoS attacks. A switching-like event-triggered communication scheme is designed to deal with intermittent DoS attacks. And a stability criterion and stability criterion for estimating the event-triggered communication parameters and obtaining the gain of the safety controller are derived.

Problems about network scheduling are shown in [24], [25], [26]. A hybrid communication scheme including time-triggered control and periodic event-triggered control is proposed for uncertain NCSs in [24].In Farayev B et al. [25], the authors propose a robust time-delay energy-constrained scheduling algorithm, using the periodic data generation characteristics of sensor nodes in the control system, to meet the time and reliability of Wireless Network Control Systems (WNCSs). In [26], a hybrid triggered scheme, which is time-triggered and event-triggered, is proposed to save network resources in NCSs.

4. Conclusion and Prospect

Researches have conducted a lot of research about problems such as network induced delay, packet dropout, network security and network scheduling, which are common in NCSs. And a lot of achievements have been obtained by the researchers. However, many problems remained still need to be further studied. When it comes to the performance of NCSs, researchers are generally supposed to focus on a single problem or relatively independent multiple problems. To meet the actual control requirements of NCSs, more attentions should be paid to other aspects in NCSs at a time. What's more, problems about safety, control performance, stability and reliability of NCSs are all needed to be improved. In general, many problems are still remained in NCSs, and challenges are still there.

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