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Data-driven predictive control for networked control systems

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ABSTRACT

This paper is concerned with the problem of data-driven predictive control for networked control systems (NCSs), which is designed by applying the subspace matrices technique, obtained directly from the input/output data transferred from networks. The networked predictive control consists of the control prediction generator and network delay compensator. The control prediction generator provides a set of future control predictions to make the closed-loop system achieve the desired control performance and the network delay compensator eliminates the effects of the network transmission delay. The effectiveness and superiority of the proposed method is demonstrated in simulation as well as experiment study.

1. Introduction

In the last decade, network technology has dramatically been developed. Recently, more and more network technologies have been applied to control systems [21,18,12,24,13,22]. This kind of control systems in which a control loop is closed via communication channel is called networked control systems. Now, networked control is a new area in control systems [4,11,15,16,9]. Particularly, Internet based control systems allow remote monitoring and adjustment of plants over the Internet, which makes the control systems benefit from the ways of retrieving data and reacting to plant fluctuations from anywhere around the world at any time. The networked control has also opened up a complete new range of real-world applications, namely tele-manufacturing, tele-surgery, museum guidance, traffic control, space exploration, disaster rescue, and health care. In networked control system (NCS), the plant, controller, sensor, actuator and reference command are connected through a network.

Most attention in this area has been paid to the design and analysis of NCSs [10,25]. The stability problem of closed-loop NCS in the presence of network delays and data packet drops has been addressed in [23,19,20]. In [1,2], the quantized feedback control and H_∞ output tracking control are analyzed respectively. To reduce the network traffic load, a sampled-data NCS scheme has been presented and some necessary and sufficient conditions for global exponential stability of the closed-loop systems via state/output feedback, without/with network delays have been established in [7]. The random network delays in the controller to actuator channel in NCSs have been studied in [5] and the fixed network delay and the random network delays in both forward and feedback channels have been considered in paper [6], but the random network delays are not in the form of a Markov process. In [8,17], the problems of stochastic stability of networked control systems with random time-delays have been discussed, in which the random time-delays are modeled as a Markov process.

In recent years, the techniques of Internet of Things are developed rapidly, the research of NCSs plays a key role in Internet of Things. The Internet of Things will draw on the functionality offered by all of these technologies to realize the vision of

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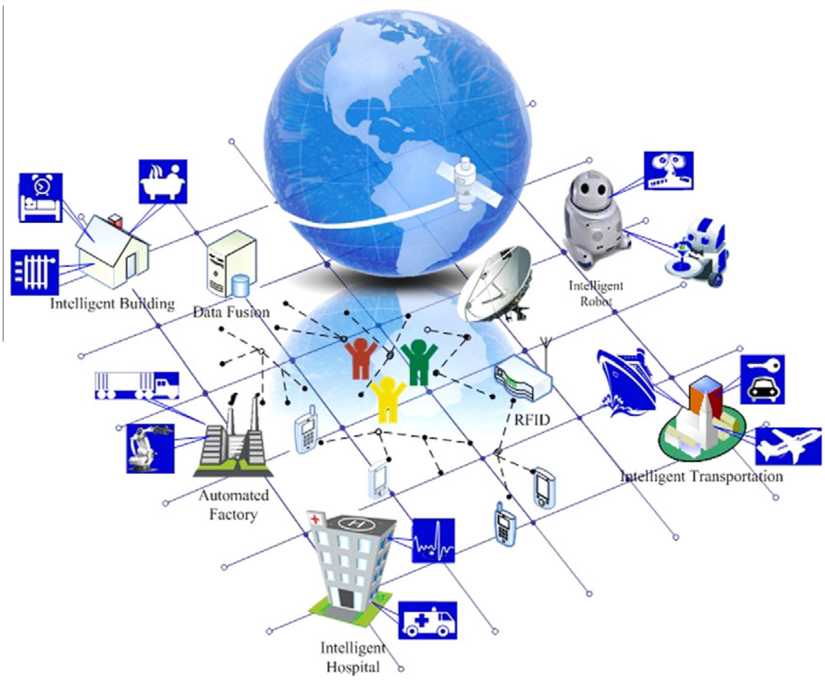

Fig. 1. Internet of things.

a fully interactive and responsive network environment. Fig. 1 shows the future applications of the Internet of Things. During the research of Internet of Things, we find data collection and processing are very important. First, it is difficult even impossible for us to get the accurate physical models of every objects in Internet of Things. The only way we know the objects in Internet of Things is data we can get. Secondly, due to the sensor technology, we can detect changes in the physical status of things. Thus, mass data about things are collected and stored. Thanks to the advances in computer science, especially in the aspects of computing ability and storage together with high quality and reliable measurements from process instruments, make it possible to collect and process the data efficiently. Finally, all the objects and devices are connected to large databases and networks—and indeed to the network of networks (the Internet). Information and commands are transmitted through network.

Under traditional design frameworks, the data from the plant are used to build the model, since dynamic models are the prerequisite of control and monitoring. Once the design of a controller or a monitor is completed, the model often ceases to exist. However, the use of models also introduces unavoidable modeling error and complexity in building the model. With emergence of the Internet of Things, mass data have to be processed. The data-driven subspace approach has been proposed for industrial process control field. The data-driven control method also can be developed for complex systems. Especially, data-driven method is particularly suitable for NCSs since only digital data can be transferred through network and received by controller and actuator. However, the use of the network will lead to intermittent losses or delays of the communicated information. These losses could deteriorate the performance and may even cause the system to go unstable. Thus, in this paper, a data-driven predictive networked controller is proposed to solve these problems without modeling.

The paper is organized as follows. In Section 2, a model based networked control system is introduced briefly. Section 3 describes the method of data-driven predictive control. In Section 4, the data-driven predictive networked control scheme is designed to the ball and beam system. The simulation and experiment examples show the effectiveness and superiority of the proposed scheme, respectively. Conclusions are provided in Section 5.

2. Brief introduction of the model based networked control systems

Consider a discrete, linear time-invariant (LTI) dynamic system S with unknown process disturbances and measurement noises, which is described in state-space form as:

$$x(k+1) = Ax(k) + Bu(k) + w(k) \tag{1}$$
$$y(k) = Cx(k) + Du(k) + \upsilon(k) \tag{2}$$

where $x(k) \in R^n$ is the system state, $u(k) \in R^l$ is the system input, $y(k) \in R^m$ is the system output, $w(k) \sim N(0, Q)$ are the unknown process disturbances and $\upsilon(k) \sim N(0, R)$ are the unknown measurement noises; A, B, C, D are constant system matrices of suitable finite dimensions.