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Event-driven observer-based control for distributed parameter systems using mobile sensor and actuator

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ABSTRACT

This paper considers the event-driven observer-based control for distributed parameter systems using mobile sensor and actuator. An observer is designed to estimate the states of the distributed parameter systems based on the measurement information provided by the mobile sensor. In order to reduce the frequency of the signal transmissions between the observer and the controller, an event-driven scheme is introduced. Once an event is generated, the event detector will send the newest observer state to the controller. Meanwhile, a guidance scheme is provided to drive the actuator to the position where the observer state reaches the maximum value to improve the control performance. For the event-driven control system, the global uniform ultimate boundedness can be guaranteed by the Lyapunov functional approach despite the reduced sampling frequency. A numerical example is finally presented to illustrate the effectiveness and the advantages of the proposed approaches.

1. Introduction

It is well known that a wide class of processes are inherently distributed in space such as chemical reactor processes, fluid flows, elastic beams, and heat conduction [1–7]. In contrast to lumped parameter systems which are described by ordinary differential equations (ODEs), these processes whose states depend on both spatial position and time are commonly called distributed parameter systems (DPSs) and modeled by partial differential equations (PDEs). In general, there are two main approaches in the investigation of the distributed parameter systems. One is to derive an approximate ODE model for the DPSs and then to apply the existing control methods for ODE systems to control the distributed parameter systems [6]. Another approach is to apply semigroup theory to analyze DPSs in Hilbert spaces [8].

From an engineering point of view, the estimation or control of distributed parameter systems can be realized through the networks of sensors and actuators which are deployed in the positions either at the interior or the boundary of the spatial domain. The network sensors are used to collect the state information and the actuators are used to dispense the corresponding control signals to the distributed parameter systems. Due to the fact that the states of the distributed parameter systems vary both spatially and temporally, it is impossible to measure and control the distributed systems in the whole spatial domain. In order to improve the estimation and/or control performance, how to deploy the limited fixed

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sensors and/or actuators, or how to find the trajectories for the mobile sensors and/or actuators should be solved. Up to now, many researchers have considered the problem. For example, the estimation or filtering problem of distributed parameter systems with the sensor scheduling has been considered in [9–17] and references therein. The control problem with the actuator scheduling is also considered by many researchers [3,18–23]. On the other hand, with the increased integration of sensor and actuator networks in distributed parameter control systems, the impact of communication constraints, such as communication delays, packet loss, sampling/transmission intervals and resource limitations, can no longer be ignored and should be accounted for. For instances, in [24], the communication delay is incorporated into the guidance scheme of the mobile sensor/actuator for performance improvement of distributed parameter systems. The missing measurements in the mobile sensor network are discussed for the estimation of a spatially distributed process [25]. However, the work on the usage of sensor and actuator networks with communication constraints for distributed parameter control systems is rather limited.

On the other hand, the event-driven control has been paid an increased attention due to the promising advantages on reducing the energy consumption in the literature [26–35]. In the event-driven control system, the necessary communication is only triggered by the occurrence of an event, so that the communication frequency among the sensors, controller and actuators can be reduced enormously. The event-driven approach has been adopted for a variety of engineering applications, such as networked control systems [26–28], multi-agent systems [29,30], wireless sensor and actuator networks [31]. For example, in [26], Yu and Antsaklis consider the event-driven output feedback for networked control systems with respect to signal quantization and network uncertainties. Several different event-driven strategies are proposed for the consensus of multi-agent models including continuous systems [29], discrete dynamics [30]. In [31], a decentralized event-triggered implementation of centralized nonlinear controllers is presented over sensor and actuator networks. Event-driven state-feedback control is discussed for continuous-time linear system with bounded disturbances [32], with communication delays and packet losses [33].

As mentioned in the above, most of the existing results on event-driven control are developed for finite dimensional dynamical systems, the mathematical models of which are expressed by the ordinary differential equations. Recently, the event-driven control approach is extended to infinite dimensional dynamical systems which are described by the partial differential equations. For instances, in [36], based on the event-driven communication strategy, Yao and El-Farra investigate a resource aware model predictive control for a parabolic distributed parameter system which is approximated by a reduced-order model. In [37], an event-driven boundary control problem is considered for linear hyperbolic systems using Lyapunov techniques. The optimal switching of the fixed actuator and controller is discussed in the distributed parameter systems using event-driven control [38]. However, the application of event-driven control theory in the distributed parameter systems is still rare. Especially, the problem of how to guide the mobile sensor and actuator in the event-based control for the distributed parameter systems has not been considered.

In this paper, we are interested in the event-driven control for the diffusion process using mobile sensor and actuator. The diffusion process like oil spills, releasing toxic gas/fog, etc. is a typical distributed parameter system and is described by a partial differential equation. The sensor which can move in the spatial domain is used to measure the concentration of the diffusion process and the actuator is used to dispense the control signals. It is assumed that the sensor has computation capacity and can perform as an estimator which can estimate the states of the distributed parameter system. Based on the state estimates, an event-driven condition is designed to determine when to transfer information from the sensor to the controller. Once an event is generated, the event detector will send the newest observer state to the controller. Here, we assume the controller and the actuator are event-driven, collocated and affixed on a mobile agent. A guidance scheme is provided to drive the actuator to the position of the maximum observer state to improve the control performance.

The remainder of the paper is structured as follows. The distributed parameter system and the dynamics of mobile sensor are introduced in Section 2, moreover, a state observer and an event-driven controller are also presented. How to guide the mobile sensor and actuator is given in Section 3. Section 4 demonstrates the global uniform ultimate boundedness of the event-driven control system and minimum inter-event time. A numerical example is given to verify the effects and advantages of our results in Section 5. In the end, a conclusion is drawn in Section 6.

2. Problem formulation

2.1. Physical plant

The physical plant is a distributed parameter system which is described by the following partial differential equation

$$\frac{\partial w(t,x)}{\partial t} = \frac{\partial}{\partial x}\left(a(x)\frac{\partial w(t,x)}{\partial x}\right) + b(x;\theta_a(t))u(t), \tag{1}$$

where $w(t, x)$ denotes the pollutant concentration as a function of time t and spatial variable $x \in \Omega = [0, l]$, along with the Dirichlet boundary value conditions $w(t, 0) = w(t, l) = 0$ and the initial condition $w(0, x) = w_0(x)$. The $a(x) > a_0 > 0$ denotes the diffusing coefficient. The functions $b(x; \theta_a(t))$ and $u(t)$ denote the spatial distribution and the control input of the mobile actuator, respectively.