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Event-triggered H_∞ filter design for delayed neural network with quantization

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ABSTRACT

This paper is concerned with H_∞ filter design for a class of neural network systems with event-triggered communication scheme and quantization. Firstly, a new event-triggered communication scheme is introduced to determine whether or not the current sampled sensor data should be broadcasted and transmitted to quantizer, which can save the limited communication resource. Secondly, a logarithmic quantizer is used to quantify the sampled data, which can reduce the data transmission rate in the network. Thirdly, considering the influence of the constrained network resource, we investigate the problem of H_∞ filter design for a class of event-triggered neural network systems with quantization. By using Lyapunov functional and linear matrix inequality (LMI) techniques, some delay-dependent stability conditions for the existence of the desired filter are obtained. Furthermore, the explicit expression is given for the designed filter parameters in terms of LMIs. Finally, a numerical example is given to show the usefulness of the obtained theoretical results.

1. Introduction

Nowadays, neural networks have been more and more prevalent due to their extensive application in image processing, associative memory, and optimization problems. Recently, many important results have been reported on neural networks, see, e.g., Gong, Liang, and Cao (2015), He, Ji, Zhang, and Wu (2016), Luo, Wang, Wei, Alsaadi, and Hayat (2016), Ma, Sun, Liu, and Xing (2016), and Yang, Li, and Huang (2016). The analysis problems of exponential stability for the delayed recurrent neural networks have stirred a great deal of research interests. Furthermore, the filtering problems for neural network systems have been widely investigated by many researchers via various methodologies (Huang, Huang, & Chen, 2013; Mathiyalagan, Anbuvithya, Sakthivel, Park, & Prakash, 2016). So the studies of the stability and filtering of delayed neural networks have significant theoretic meaning and application value. In recent years, several methods have been proposed to solve the H_∞ filter design problem (Cao, Sun, & Lam, 1998; Huang & Feng, 2009; Liu, Fei, Tian, & Gu, 2015; Wang & Ho, 2003; Wang, Shi, & Zhang, 2015). The authors in Liu et al. (2015) investigate the reliable H_∞ filter design for a class of $T-S$ fuzzy systems with stochastic sensor faults under an event triggered scheme. In the literature (Wang & Ho, 2003), the problem of H_∞ filtering of nonlinear stochastic systems is also considered. As the basic problem in the area of network, H_∞ filter problem has received researchers' attention for a long time, but the study on neural network only has a short history, many problems should be studied widely and deeply. Therefore, it is essential to pay attention to filter design in the various aspects of the neural network.

As an alternative of the time-triggered control scheme, event triggered scheme is utilized as an efficient way to reduce the burden of communication networks and improve the transmission efficiency. Compared with the time-triggered control scheme, the advantage of the event triggered scheme is that it can facilitate the efficient usage of the shared communication resources, and whether the current sampled information will be transmitted or not depends on pre-designed conditions, avoiding much of the unnecessary transmission. Up to now, event triggered scheme has received a lot of research interest and some important results have been published (Hu & Yue, 2012a; Li et al., 2016; Liu et al., 2015; Liu & Yue, 2013b; Yue, Tian, & Han, 2013). To name a few results, the authors in Yue et al. (2013) proposed a novel event-triggering scheme and event-triggered H_∞ controller design for

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networked control systems which are investigated. Based on the results of Yue et al. (2013), the authors in Liu and Yue (2013b) propose an event-triggering sampling strategy with probabilistic sensor and actuator fault and investigate the reliable control design for networked control system under the proposed event-triggered scheme. In Hu and Yue (2012a), the authors are concerned with the problem of event-based H_∞ filtering for networked systems with communication delay. In Liu et al. (2015), the authors investigate reliable H_∞ filter design for a class of $T - S$ fuzzy systems with stochastic sensor faults under an event triggered scheme. The authors in Li et al. (2016) consider the event-triggered distributed average-consensus of discrete-time first-order multi agent systems with limited communication data rate and general directed network topology. Motivated by the above references, it is necessary to design an event-triggered communication scheme to save the limited communication resources in the delayed neural network system. This is one of the motivations of this work.

At present, the quantitative processing has been paid attention by more and more researchers. Considering the limited communication capacity in the networks, quantization of measurement and/or input signals is an indispensable step which aims at saving limited bandwidth and energy consumption. It can be considered as the process of encoding, which is realized by the quantizer. Quantization plays an important role in information exchange among agents. In the literature (Hu & Yue, 2012b; Li, Chang, Du, & Yu, 2016; Li, Chen, Liao, & Huang, 2016), a series of quantitative methods are proposed in time-varying quantizer or logarithmic quantizer. In Li, Chang et al. (2016), the authors introduce H_∞ control of discrete-time for uncertain linear systems with quantized feedback. The authors in Hu and Yue (2012b) discuss the event-triggered control design of linear networked systems with quantization. In the literature (Li, Chen et al., 2016), quantized data-based leader-following consensus of general discrete-time multi-agent systems is described. The effect of the quantization on the networked control systems is much larger than the traditional control systems. To the best of our knowledge, event-triggered scheme for a class of neural network systems with quantization has not been well addressed. This situation motivates our current investigation.

Motivated by the observations above, we focus on the event-based H_∞ filter design problem for a class of delayed neural networks with quantization. To reduce the computation load or to reduce the exchange of information, we introduce an event-triggering sampling mechanism. Then, an event-based filter design model for neural network systems is constructed by taking the effect of event-triggered scheme and the quantization into consideration. Besides, sufficient conditions for the existence of the filter are established and the explicit expression is given for the designed filter parameters. Finally, a numerical example is given to show the effectiveness.

The paper is organized as follows. In Section 2, an H_∞ filter design is addressed for the delayed neural network systems with event triggered communication scheme and quantization. Sufficient conditions for the existence of the desired filter are established and a filter design method is provided in Section 3. Moreover, we derive the explicit solution of filter parameters. A numerical example is given in Section 4 to show the effectiveness and applicability of the proposed method. The conclusion is drawn in the final part.

Notation: In this paper, $\mathbb{R}^n$ and $\mathbb{R}^{m\times n}$, respectively, denote the n-dimensional Euclidean space and the set of $m \times n$ real matrices. Matrix $X > 0$ (respectively, $X \geq 0$) denotes that X is a real symmetric positive definite (positive semi-definite). In a symmetry matrix $*$ is used to describe the symmetric terms. I is the identity matrix of appropriate dimension. In addition, T stands for the transpose of matrix.

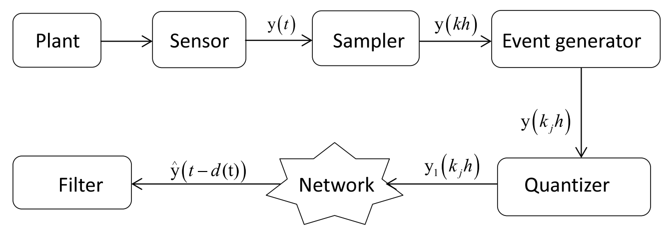

Fig. 1. The structure of event-triggered H_∞ filter design for delayed neural network with quantization.

2. Problem formulation and preliminaries

As is shown in Fig. 1, consider a delayed neural network with n neurons:

$$\begin{cases} \dot{x}(t) = -Ax(t) + W_0 g(x(t)) + W_1 g(x(t-\tau(t))) + A_w \omega(t) \\ y(t) = Cx(t) \\ z(t) = Lx(t) \end{cases} \quad (1)$$

where $x(t) = [x_1, x_2, \ldots, x_n]^T \epsilon \mathbb{R}^n$ is the state vector of the neural network; $A = \mathrm{diag}\{a_1, a_2, \ldots, a_n\}$ is a diagonal matrix with positive entries $a_i > 0$; W_0 and W_1 are the connection weight matrix and the delayed connection weight matrix, respectively; $g(x(t)) = [g_1(x_1(t)), g_2(x_2(t)), \ldots, g_n(x_n(t))]^T$ denotes the neuron activation function; and $\tau(t)$ denotes the time-varying bounded state delay satisfying $\tau(t)\epsilon[\tau_m, \tau_M]$, where τ_m and τ_M are the lower and upper bounds of $\tau(t)$; $\omega(t)\epsilon\mathbb{R}^p$ is the external disturbance and $\omega(t)\epsilon L_2[0,\infty)$; A_w, C, L are the parameter matrices with appropriate dimensions; $y(t) = [y_1, y_2, \ldots, y_r]^T \epsilon \mathbb{R}^r$ is the measurement output; $z(t) = [z_1, z_2, \ldots, z_p]^T \epsilon \mathbb{R}^p$ is the objective vector.

Event generator is introduced between the sensor and the quantizer which is used to determine whether the newly sampled state will be sent out to the quantizer by using the following judgement algorithm, which is the same as Yue et al. (2013)

$$[y((k+j)h) - y(kh)]^T \Phi [y((k+j)h) - y(kh)] \\ \leq \sigma y^T((k+j)h)\Phi y((k+j)h) \quad (2)$$

where the Φ is a symmetric positive define matrix, $j = 1, 2, \ldots$, $\sigma\epsilon[0, 1)$, $y((k+j)h)$ is the current sampled sensor measurements, and $y(kh)$ is the latest transmitted sensor measurements. The sampled state $y((k+j)h)$ satisfying the inequality (2) will not be transmitted, only the one that exceeds the threshold in (2) will be sent to the quantizer, which means that, in the sensor side, only some of the sampled states that violate (2) will be sent out to the quantizer side.

Remark 1. From the event-triggered algorithm (2), we can easily see that the sensor measurements are sampled at time kh by sampler with a given period h, the next sensor measurement is at time $(k+1)h$. Suppose that the release times are k_0h, k_1h, k_2h, $\ldots$, it is easily seen that $t_ih = k_{i+1}h - k_ih$ denotes the release period of event generator in (2), t_ih means that the sampling between the two conjoint transmitted instant.

Remark 2. It is easily seen from event-triggered algorithm (2) that the set of the release instants $\{k_0h, k_1h, k_2h, \ldots\} \subseteq \{0, 1, 2, \ldots\}$. The amount of $\{k_0h, k_1h, k_2h, \ldots\}$ depends on the value of σ and the variation of the sensor measurements.

When the new sampled states $y(k_jh)$ arriving at the quantizer, we determine to quantize $y(k_jh)$. Define a function (Qu, Guan, He, & Chi, 2015)

$$q(y) = \mathrm{diag}\{q_1, q_2, \ldots, q_m\} \quad (3)$$

where $q_i(\cdot)$ is symmetric, i.e. $q_i(-y_i) = -q_i(y_i)$, and the logarithmic quantizer can be described by the following sector mode:

$$q_i(y_i) = (1 + \Delta_{q_i}(y_i))y_i. \quad (4)$$