Applied Mathematics and Computation 316 (2018) 205–214

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Network-based $\mathcal{H}_\infty$ state estimation for neural networks using imperfect measurement

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ARTICLE INFO

Keywords:
Neural network
State estimation
$\mathcal{H}_\infty$ control
Sampling
Transmission delay
Packet dropout

ABSTRACT

This study considers the network-based $\mathcal{H}_\infty$ state estimation problem for neural networks where transmitted measurements suffer from the sampling effect, external disturbance, network-induced delay, and packet dropout as network constraints. The external disturbance, network-induced delay, and packet dropout affect the measurements at only the sampling instants owing to the sampling effect. In addition, when packet dropout occurs, the last received data are used. To tackle the imperfect signals, a compensator is designed, and then by aid of the compensator, $\mathcal{H}_\infty$ filter which guarantees desired performance is designed as well. A numerical example is given to illustrate the validity of the proposed methods.

1. Introduction

The study on nonlinear systems have been becoming more and more important because nonlinear phenomena are ubiquitous [1]. As one of representative nonlinear systems, recently, neural networks have drawn much attention because they have been successfully applied in diverse research fields such as clouding computing, power network, associative memories, signal processing, pattern recognition, smart antenna arrays, and so on [2–9]. To use neural networks in these applications, exact information of the neuron states is needed. In general, this goal can be achieved by designing a certain state estimator [10–21].

Communication technology is rapidly growing nowadays, so the sensed neuron states are usually transmitted through networks, so a necessity for research on network-based state estimation naturally arises. Network-based state estimation offers several benefits compared with traditional state estimation, such as flexible architecture, low cost, simple installation and maintenance. However, it also has several undesired factors caused by the networks, such as external disturbance, transmission delay, and packet dropout. In practice, the network is not always ideal due to the limited bit rate by busy channels and abrupt changes of the network circumstances or customer requests. These disadvantages are unavoidable and bring some significant problems such as the instability, poor performance of the system, and so on.

When we exchange data through network channels, digital sensors are commonly used for sensing exact values of targets. If the targets are continuous-time systems, then continuous-time signals are captured by digital sensors at only the sampling

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http://dx.doi.org/10.1016/j.amc.2017.08.034
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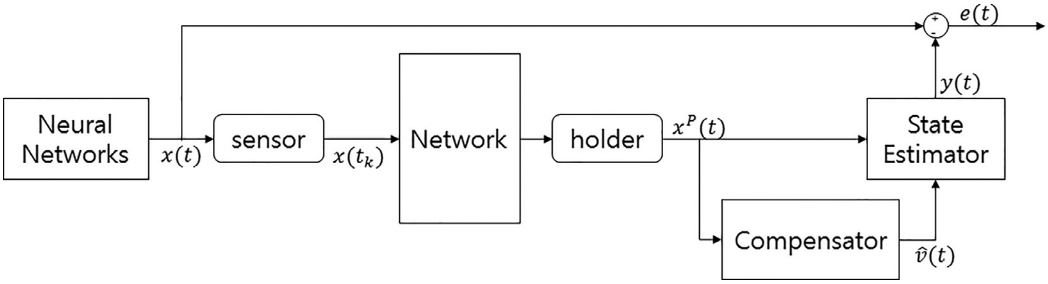

Fig. 1. The systematic structure.

instants t_k. After passing through a sensor, the continuous-time signals become discrete-time signals with a sampling period $t_{k+1} - t_k$. The combination of a sampling effect and network-induced undesired factors (external disturbance, transmission delay, packet dropout) leads to other problems. Because of the sampling effect, sensed data can be transmitted at only the sampling instants, so the network-induced external disturbance and transmission delay occur at only sampling instants too. For example, for network-induced external disturbance and transmission delay $w(t)$ and $\tau(t)$, $w(t_k)$ and $\tau(t_k)$ are affected to the transmitting data.

Packet dropout is a more important factor for the sampled signal because if the packet dropout occurs at the present sampling instant, then packets will disappear until the next sampling instant. For example, if a packet dropout occurs during $t \in [t_1,\ t_{d_1})$, where $t_1 < t_{d_1} < t_2$ and t_k $(k = 1, 2, \ldots)$ is a sampling instant, then the packet dropout will occur during $[t_1\ t_{d_1})$ in the case of a continuous-time signal, but in the case of a sampled signal, packet dropout will occur during $[t_1\ t_2)$. Because of these issues, the final transmitted signals will be quite different from the original one and contain a large amount of network uncertainty. Thus, it is clear that solving a state estimation problem using network-constrained measurements is very difficult.

Most research has handled these network constraints individually [14–21]. Zhu et al. [14] investigated the $\mathcal{H}_\infty$ state estimation problem for discrete-time switching neural networks in which mode-dependent time-varying delays and a new concept, persistent dwell time switching regularities, were considered. The measurements included random packet dropout and disturbance. Huang et al. [16] used measurements that contain delay and disturbance and designed the Arcak-type guaranteed $\mathcal{H}_\infty$ state estimator for neural networks with a time-delay. In [19], based on the discontinuous Lyapunov approach, the stochastic sampled-data controller was designed for estimating states of neural networks with a time-varying delay. To the best of our knowledge, there is no report on the state estimation of neural networks via network-constrained measurements that simultaneously includes the sampling effect, external disturbance, transmission delay, and packet dropout.

From above discussion, it is clear that there is a strong need to figure out original signals, because the final measurements would be quite different with original signals when original signals are sensed and transmitted through a network. For example, if we construct a model (or state estimator) from these measurements to copy the original neural networks and install it to an industrial plant, then it cannot provide expected control performance or sometimes cause serious problems because the constructed neural network model cannot copy the same outputs with original one. As these reasons, it is very important to estimate actual state information of neural networks with high accuracy. For this situation, this paper addresses the followings:

- Consider imperfect measurements
  This paper designs a $\mathcal{H}_\infty$ state estimator by considering four issues, sampling effect, external disturbance, transmission delay, and packet dropout, simultaneously. To design a state estimator in the existence of these four issues simultaneously is one of the main contributions of this paper because most of design problems of the state estimator have been solved by considering these items individually.
- Design a compensator
  Usually, to reduce the effects of external disturbance under a certain acceptable value, the $\mathcal{H}_\infty$ control method is adopted. However, this paper considered four issues, so only using $\mathcal{H}_\infty$ technique could not provide aimed performance. As a solution to improve the estimation accuracy, we design a compensator to compensate network uncertainties, and then, a state estimator is designed using the output of the compensator.
- When signals transmitted through a network, it firstly sensed by sensor and send in digital format. For this case, if sampling information of sensor is accessible, then sampling issue can be easily handled by using the information. However, if we cannot know the sampling information due to aging of devices, abrupt changes of circumstances, the sampling is an issue. Therefore, in this paper, we consider both cases and derived robust criteria for each cased.

Throughout this paper, when packet dropouts happen, the last received data will be used in the estimator because of the existence of the Zero-Order-Hold (ZOH). Both design problems of the network-based $\mathcal{H}_\infty$ state estimator and compensator are solved by deriving new sufficient conditions in terms of a linear matrix inequality (LMI) based on Lyapunov approach.