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Effective Adaptive Kalman Filter for Network Control Systems with Network Delay Influence

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Abstract
In this paper, we consider an Effective adaptive Kalman filter for network control systems with network delay influence. By concerning network delays with random transmission delays, while modeled a residual signal in which fault free is hypothetical to stability and identically zero. In the real world, these conditions are not satisfied due to various factors such as parameter uncertain systems with stochastic packet dropout, noise measurements, and induced delay. Effective performance analysis of fault diagnosis is illustrated. An effective adaptive Kalman filter, which is with a time-varying, is designed to minimize the outcome of the network.

Keywords: Network control systems, Time-varying, residual signal

Introduction

Network control system (NCS), or control over the network is a network-based system with a closed-loop which the sensor, actuator, and controller are connected in a form of information packets through a network. NCS has become a widely used technology in control areas and has attracted significant attention in the past few years[1]. Different from the traditional point-to-point control systems, NSC possesses many advantages that communication networks have, such as low cost, reduced weight and power requirements, simple installation, simple maintenance and shared information. Despite many advantages, when data is transmitted over the communication networks with infinite bandwidth, random delay, and packet dropout
will inevitably deteriorate the performance of NCS and even lead to losing stability [2]. NCS has been applied in various areas such as automotive, traffic systems, medical treatments, advanced aircraft and so on [3].
The study on filters and controller design for networked control systems with the consideration of various uncertainties in data transmission in the network has received a lot of attention in recent years [4-5]. Packet dropout can be traced back to Nahi[6] and Hadidi[7] where the phenomenon of packet loss is described as uncertainties by scalar binary random variables. Recently, this problems has been studied using erratic observations models, Such as optimal H_2 filtering in network control systems with multiple packet dropout, Sun and xie have reprented multiple packet dropout modelling method, robust filtering and nonlinear H_∞filtering are designed for the multiple missing measurement via linear matrix inequality (LMI) respectively[8-11].
This paper is prearranged as follows. In section 2, we present the problem formulation and preliminaries in network control systems. Section 3, Effective adaptive Kalman filter is designed for residual generation

Problem Formulation and Preliminaries

By considering the following linear time-invariant system:

$$\begin{cases} x(t) = Ax(t) + Bu(t) + Df(t) + Ed(t), \\ y(t) = Cx(t), \end{cases} \qquad (1)$$

Where$x(t) \in R^n$,$u(t) \in R^n$, $y(t) \in R^r$ denote the system state vector and output vector, respectively. $d(t) \in R^n$ is the external disturbance which belongs to $l_2[0, +\infty)$.$f(t) \in R^s$ is the fault signal. A, B, C, D, E are real matrices of the appropriate dimensions.

Fig.1 shows the structure of the mentioned NCS.

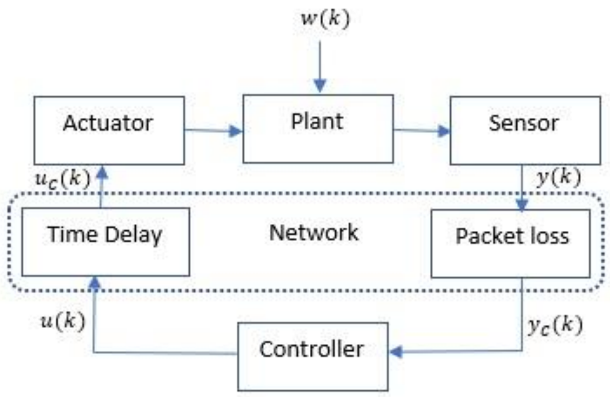


Fig.1: Structure of NCS with random delay and packet dropout

The measurement $y(t)$ is time-stamp and transmitted through a digital communication network (DCN), Whose goal line is to transport packet from source to destination. The DCNs are very complex, and thus sensor -controller delay or controller-actuator delay is unavoidable between the senders and the receiver. Since the networks, Induced delays depends severely on variable networks conditions[12], They are usually time-varying, random and unknown but upperbounded.
The discretization model of the network-induced delay and the control input (Zero holds is assumed) over a sampling interval $[kT, (K+1)T]$:

$$U_t = \begin{cases} U_{k-1}, t \in [kT, kT + \tau_k]; \\ u_k, t \in [\, kT + \tau_k, (K+1)T]. \end{cases}$$

By reasonable assumption, the noise vector components are affected by slow dynamic, meaning:

$$f_t = f_k,\ d_t = d\ \forall t \in [kT, (k+1)T], \qquad (2)$$

The discretization of plant model (1) over one sample period is given as:

$$\begin{cases} x_{k+1} = \Phi x_k + \Gamma_0 u_k + \Gamma_1 u_{k-1} + \Xi d_k + \Psi f_k \\ yk = cx_k \end{cases} \quad (3)$$

Where:

$$\Phi = e^{AT},\ \Psi = \int_0^T e^{As} F ds,\ \Xi = \int_0^T e^{As} E ds$$

$$\Gamma_0(\tau_k) = \int_0^{T-\tau_k} e^{As} B ds,\ \Gamma_1(\tau_k) = \int_{T-\tau_k}^{T} e^{As} B ds$$

By property of definite integral from equation (4), we get

$$\begin{cases} x_{k+1} = \Phi x_k + \Gamma u_k + \Gamma_{1\Delta u_k} + \Psi f_k + \Xi d_k \\ yk = Cx_k \end{cases} \quad (4)$$

With the following definition:

$$\Delta u_k = u_{k-1} - u_k,\ \Gamma = \int_0^T e^{AS}\,\mathrm{B}ds \qquad (5)$$

There exist a time-varying term $\Gamma_{1\Delta u_k}$ in the state evolution equation of system (4) which makes it usual sampled-data system. Therefore, the traditional strategies of detecting and isolating multiple faults must be re-eveluated for the NCS. When the sampling period T is suffient small compared with the system's time constant, by using the Taylor approximation of e^{AS} we get:

$$\Gamma_1(\tau_k) = \int_{T-\tau_k}^{T} e^{AS}\mathrm{B}ds$$

$$= A^{-1}[1 - e^{-A\tau_k}]e^{AT}B \approx \Phi B_{\tau_k} \qquad (6)$$

Finally, the discrete-time model of the Networked control System is given by:

$$\begin{cases} x_{k+1} = \Phi x_k + \Gamma u_k + (\Phi B \Delta u_k)\tau_k + \Psi f_k + \Xi d_k \\ yk = Cx_k \end{cases} \quad (7)$$

The goal of the failure diagnosis System is to design a residual which is zero in the fault-free case and nonzero when a fault has occurred. The problem to deal with is to design a linear filter whose inputs are the measurable outputs and control inputs which generates certain outputs called residual signals, one for each possible fault, not affected by other faults and not affected by disturbances.
Therefore, our aim is to find an observer for the system (1) of the form:

$$\begin{cases} \hat{x}_{k+1} = \Phi \hat{x}_k + \Gamma u_k + H(y_k - c\check{x}_k) \\ \check{y}k = C\check{x}_k \end{cases} \quad (8)$$

From (8) and (3), the state estimation error

$e_x = x_k - \check{x}_k$ Propagate as:

$$e_{k+1} = \left(\Phi - HC\right)e_k + \Phi B\tau_k\Delta u_k + \Xi d_k + \Psi f_k \quad (9)$$

The term Φ ⍰$B\tau_k\Delta u_k$, which is due to the influence of the network, will have an impact on the quality of residuals.

Design of Effective Residual Generator

In this section, our goal is to design an effective residual generator similar to the one described in equation (9).
Yue and Ding suggest considering a time-varying space-based residual generator in [13-16], where robustness is achieved thanks to a decoupling procedure.
By assuming that the network delay can be disintegrated into a deterministic and stochastic part

$$\tau_k = \bar{\tau} + \Delta\tau_k \quad (10)$$

Where the stochastic parts belong to Zero mean white Gaussian sequence with well know variance var$(\Delta\tau_k) = \sigma^2$ from (10) and according to (7)
We have

$$\begin{cases} X_{k+1} = \Phi X_k + \Gamma u_k + \Phi B\bar{\tau}\Delta\tau_k + \Phi B\Delta\tau_k\Delta u_k \\ \quad + \Xi d_k + \Psi f_k \\ y_k = Cx_k + w_K \ (11) \end{cases}$$

Then the NCS model can be written as:

$$\begin{cases} X_{k+1} = \Phi X_k + \left[\Gamma \ \Phi B\bar{\tau}\right]\begin{bmatrix} u_k \\ \Delta u_k \end{bmatrix} + \left[\Xi\Phi B\Delta \, u_k\right] \\ \begin{bmatrix} d_k \\ \Delta\tau_k \end{bmatrix} + \Psi f_k \\ y_k = Cx_k + w_K \ (12) \end{cases}$$

And with:

$$\widetilde{\Gamma} = \left[\Gamma \ \Phi B\,\bar{\tau}\right], \tilde{u}_k = \begin{bmatrix} u_k \\ \Delta u_k \end{bmatrix}$$

$$G_k = \left[\Xi\Phi B\Delta \, u_k\right], V_k = \begin{bmatrix} d_k \\ \Delta\tau_k \end{bmatrix}$$

We get:

$$\begin{cases} X_{k+1} = \Phi X_k + \widetilde{\Gamma}\tilde{u}_k + G_k V_k + \Psi f_k \\ y_k = Cx_k + w_K \end{cases} \quad (13)$$

With the following indicator i=V_k *and* w_k are two discrete gaussian white noise such as

$E[w_k] = 0$, $E[V_k] = 0_{d+1}$

And:

$E[w_k w_j^T] = Q.\delta_{kj}$, $E[V_k V_j^T] = \tilde{R}.\delta_{kj} \ i \neq j$

$$\tilde{R} = \begin{bmatrix} R & 0 \\ 0 & \sigma^2 \end{bmatrix}$$

ii= $\{w_k\}$ refered as measurement noise sequence and $\{V_j\}$ refered as to system noise sequence are not correlated :

$$E\left[w_k V_j^T\right] = 0 \ \forall k, j$$

Iii: The initial state X_0 is the random gaussina variable of m_0 mean and matra ix of covariance P_0 and

$$E[x_0] = m_0, E[(x_0 - m_0)(x_0 - m_0).^T] = P_0$$

iv: The initial state x_0 and noise V_k *and* w_k are not correlated

$$E\left[x_0 V_j^T\right] = m_0, E[x_0 - W_K^T] = 0$$

V= the matric Φ, $\tilde{\tau}$, C, G are certain [17-18]

With the model of NCS, given by (Eq….) and for the residual generation, it is proposed to generate residual using the effective adaptive Kalman filter given by the recursive algorithm:

$$\begin{cases} \hat{x}_{k+1/k} = \Phi \hat{x}_{\frac{k}{k}-1} + \tilde{T}\tilde{u}_k + \Phi K_k \left(Y_k - C\hat{x}_{\frac{k}{k}+1}\right) \\ K_k = P_{\frac{k}{k}-1} C_0^T \left(CP_{\frac{k}{k}-1} C^T + R\right)^{-1} \\ P_{k+1/k} \Phi P_{\frac{k}{k}-1} \Phi^T + G_k \tilde{R} G_k^T - \Phi K_k C P_{\frac{k}{k}-1} \Phi^T \end{cases}$$

From () and () the state estimation error $e_k = x_k - \hat{x}_k$ is propagating as:

$$e_{k+1} = \left(\Phi - \Phi K_k C\right) e_k + \Phi B\Delta T_K \Delta u_k + \Xi d_k + \Psi f_k$$

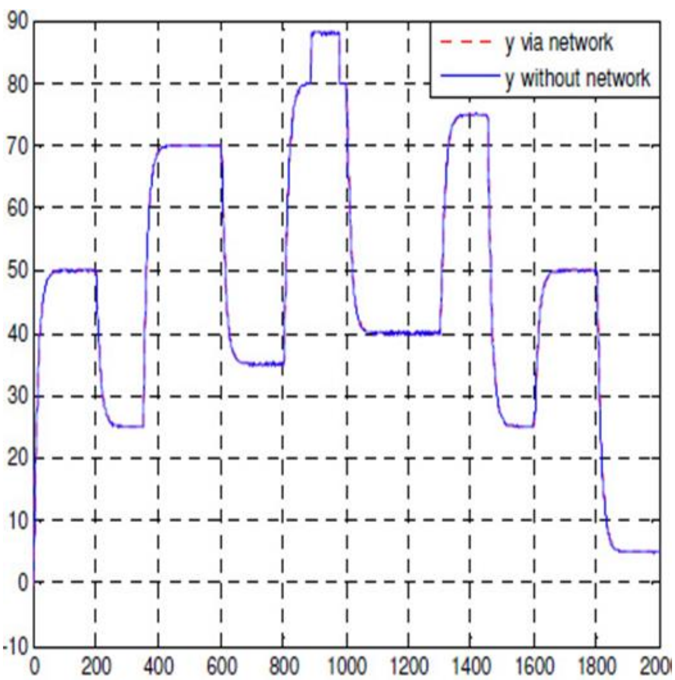
The proposed residual generator is effective as long as we can fix the threshold detection in function of the term $\Phi B\Delta \ \Phi B\Delta \ \tau_k \Delta u_k$

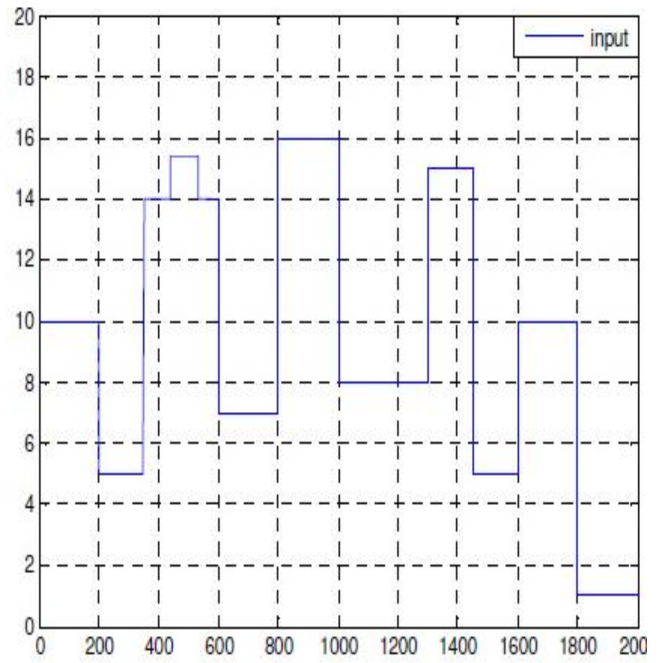
Numerical Example

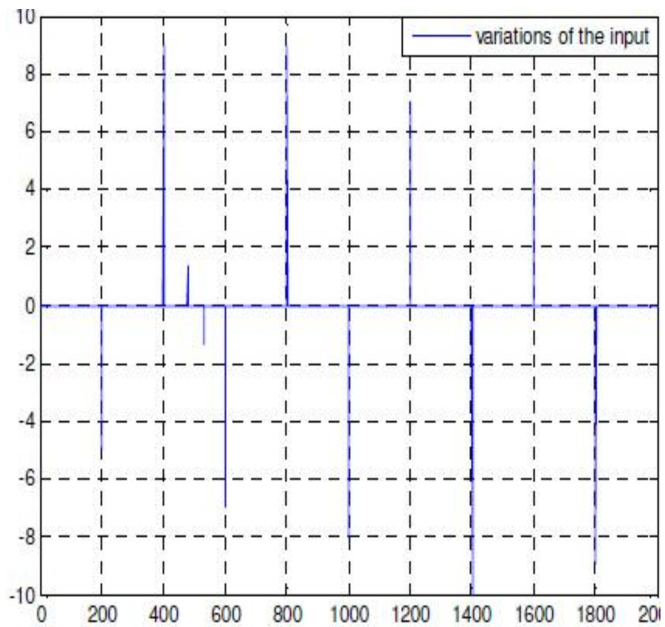
Table 1: System Parameters

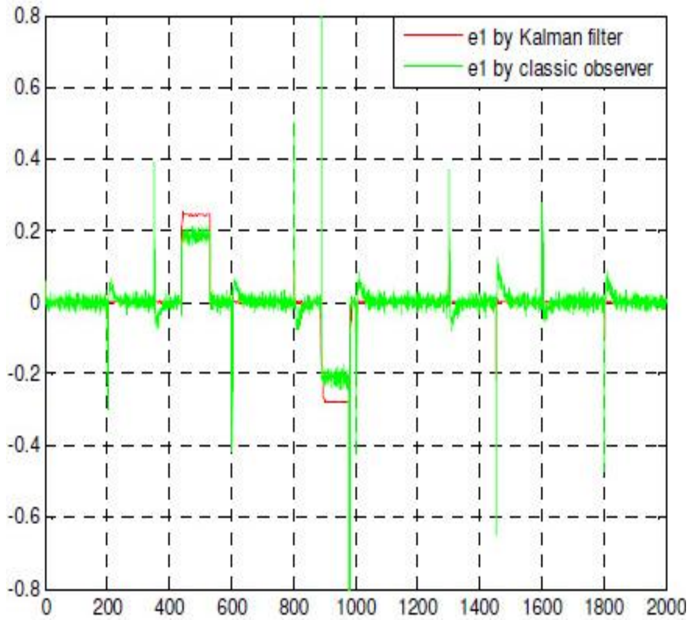
J	Inertia	2 kgm^2
k	Back-EMF constant	1 Vs/rad = 1 Nm/A
R_m	Resistance	0.4 ohm
R_G	Resistance	0.4 ohm
a	Constant	100
L	Inductance	5 H
r	Resistance	20 ohms

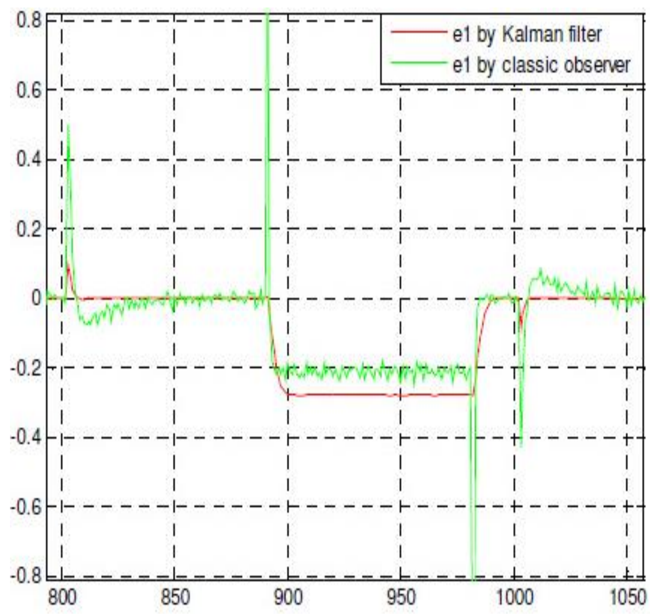
The process is controlled via network; where the communicatipn delay τ is supposed to be guassian.











Conclusion

In this paper a proposed designed effective adaptive Kalmar filter for residual to minimize the impact of data delays. The main problem address is the robustness against network delays. The validation and comparison to classical Leuenberger state observer result show how the effectiveness of the designed system.

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