

Failure Detection of Actuator Using Extended Semi-strongly Stabilizing Controllers

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Abstract

In this paper, by adapting the extended semi strongly stabilizing controller by Kimura et al. to a self-repairing system with failure detection, we propose the control system with failure detection using resonance. A design procedure for the control system with failure detection is presented. The results of this paper enable the construction of a reliable system that detects failure and repairs itself.

Keywords

Resonance, Extended semi-strongly stabilization, Parameterization

1. Introduction

A strongly stabilization is a control method to make control systems stable using stable controllers. Using this method, it is possible to construct a highly reliable control system, since it has robustness. However, when a strongly stabilizing controller is used, steady-state error remains when step disturbances and uncertainties exist in the control system because the strongly stabilizing controllers do not have a pole on the origin. To solve this problem, Hoshikawa et al. (2012) expanded the concept of strongly stabilization and proposed a concept of semi strongly stabilization using a controller which has a pole at the origin and the others in the open left half-plane. In addition, a class of semi-strongly stabilizable plants and a design method of controllers are proposed (2015). However, the method by Hoshikawa et al. fails to place the poles on the imaginary axis. There exist control systems that need a pair of poles on the imaginary axis; for example, the control systems follow the sinusoidal signals and the self-repairing control systems with faulty sensors (Takahashi 2018). To overcome this problem, Kimura et al. (2023) give a definition of an extended semi-strongly stabilizing controller that has a pair of poles on the imaginary axis and no other unstable poles. Then, Niiyama

et al. proposed a design method of a control system for failure detection method using the extended semi-strongly stabilizing controller. However, the extended semi-strongly stabilizing controller does not have a pole at the origin, so the control system proposed Niiyama et al. could not eliminate the steady-state error from the output. Kimura et al. (2023) redefined the extended semi-strongly stabilizing controller with a pole at the origin, a pair of poles on the imaginary axis and no other unstable poles. However, since in the control system with failure detection proposed by Niiyama et al., an auxiliary input is added to the control system, the effect of the auxiliary input remains on the output. Therefore, applying the extended semi-strongly stabilizing controller proposed by Kimura et al. into failure detection system does not completely eliminate the steady-state error. In order to this solve problem, Kimura et al. (2023) redefined the extended semi-strongly stabilizing controller which have a pole at the origin, two pairs of poles on the imaginary axis and stable poles.

In this paper, we propose a designing method of control system with actuator failure detection using the extended semi-strongly stabilizing controller proposed by Kimura et al. (2023) The proposed method makes it possible to construct a reliable system to detect and repair actuator failures.

2. Problem formulation

Consider the control system written by

$$\begin{cases} y(s) = G(s)u(s) + d(s) \\ u(s) = C(s)(r(s) - y(s)) \end{cases} \quad (1)$$

where $G(s) \in R(s)$ is the plant. $C(s) \in R(s)$ is the controller, $y(s)$ is the output, $u(s)$ is the control input, $d(s)$ is the disturbance and $r(s)$ is the step reference input, that is,

$$r(t) = r_0 \in R. \quad (2)$$

$G(s)$ is assumed to be extended semi-strongly stabilizable. That is, from Kimura et al. (2023), $G(s)$ is written by the form

$$G(s) = \frac{N_b(s) + N_c(s)Q_2(s)}{\frac{1 - N_b(s)Q_1(s)}{N_c(s)} - Q_1(s)Q_2(s)}. \quad (3)$$

Here, $N_c(s) \in RH_\infty$ is written as

$$N_c(s) = \frac{s(s^2 + \omega^2)^2}{n_{cd}(s)}, \quad (4)$$

where $\omega \in R$ is any constant real number, $n_{cd}(s)$ is any Hurwitz polynomial of 5 degree. $Q_1(s) \in RH_\infty$ is any function satisfying

$$Q_1(s)|_{s=0, \pm j\omega} \neq 0, \quad (5)$$

$N_b(s) \in RH_\infty$ is any function satisfying

$$\frac{1}{s^2 + \omega^2} \{1 - N_b(s)Q_1(s)\} \Big|_{s=0, \pm j\omega} = 0 \quad (6)$$

and

$$N_b(s)|_{s=0, \pm j\omega} \neq 0. \quad (7)$$

$Q_2(s) \in RH_\infty$ is any function.

It is supposed that the control system has two actuators: the original actuator and the backup actuator. Initially, the original actuator is used. Actuator failure occurs at time $t = t_f$. That is, after $t = t_f$, the correct control inputs are not operated to the plants, the control input $u(t)$ is assumed to be

$$u(t) = u_f \quad (t \geq t_f), \quad (8)$$

where $u_f \in R$ is constant real number. When the system detects that the original actuator has failed, it switches from the original actuator to a backup actuator. Even if $C(s)$ is designed to stabilize the control system in (1), the actuator failures sometimes make the control system in (1) unstable and the required control characteristics cannot be obtained. If we can detect failures of the control system in (1), the control system in (1) becomes a highly reliable control system. The problem considered in this paper is to design the control system with actuator failure detection using an extended semi strongly stabilizing controller proposed by Kimura et al. (2023).

3. Control system

In this section, using the parameterization of all extended semi-strongly stabilizing controllers with a pole at the origin and a pair of poles on the imaginary axis, we propose the control structure of the control system with actuator failure

detection. From Kimura et al. (2023), for the extended semi-strongly stabilizable plant $G(s)$ in (3), the parameterization of all extended semi-strongly stabilizing controllers $C(s)$ can be expressed by

$$C(s) = \frac{Q_1(s) + \left\{ \frac{1 - N_b(s)Q_1(s)}{N_c(s)} - Q_1(s)Q_2(s) \right\} P(s)}{N_c(s) - \{N_b(s) + N_c(s)Q_2(s)\}P(s)}, \quad (9)$$

where $P(s) \in RH_\infty$ and $Q(s) \in RH_\infty$ are functions written as

$$P(s) = N_c(s)Q(s), \quad (10)$$

and

$$Q(s) = \frac{1 - \hat{Q}(s)}{N_b(s) + N_c(s)Q_2(s)}, \quad (11)$$

respectively, $\hat{Q}(s) \in \mathcal{U}$ is an unimodular function that makes $Q(s)$ proper and satisfies

$$\frac{1}{(s - s_i)^{m_i-1}} \{1 - \hat{Q}(s)\} \Big|_{s=s_i} = 0 \quad \forall i, \quad (12)$$

where $\mathcal{U}$ denotes the set of all unimodular functions, $s_i \in R$ is unstable zero of $n_b(s) + n_c(s)Q_2(s)$ and m_i is its multiplicity.

When $N_c(s)$ in (9) is settled by

$$N_c(s) = \frac{s(s^2 + \omega^2)^2}{(Ks^2 + \zeta s + K\omega^2)(s + \sigma)^3} \quad (13)$$

and $C(s)$ is given by (9), the control structure with actuator failure detection is proposed as shown in Figure 1.

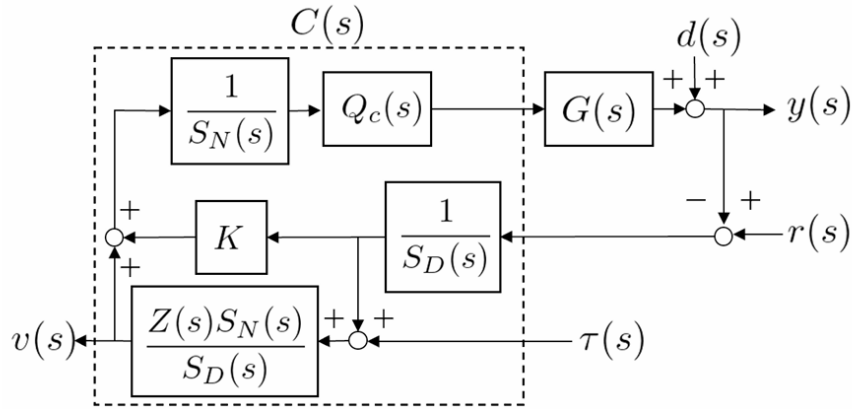


Figure 1. Feedback control system with failure detection

Here $\tau(s) = \mathcal{L}\{\tau(t)\}$, $\tau(t)$ is an auxiliary signal written by

$$\tau(t) = \delta \sin(\omega t), \quad (14)$$

where $\delta > 0$, $v(s) = \mathcal{L}\{v(t)\}$, $v(t)$ is the detector output that determines whether or not, the actuator has failed and $Z(s)S_N(s)/S_D(s)$ is a detector. $Q_c(s) \in RH_\infty$, $S_N(s) \in RH_\infty$, $S_D(s) \in RH_\infty$, and $Z(s) \in RH_\infty$ are written by

$$Q_c(s) = Q_1(s) + \frac{Q(s)}{1 - (N(s) + N_c(s)Q_2(s))Q(s)}, \quad (15)$$

$$S_N(s) = \frac{s}{s + \sigma}, \quad (16)$$

$$S_D(s) = \frac{s^2 + \omega^2}{(s + \sigma)^2} \quad (17)$$

and

$$Z(s) = \frac{\zeta}{s + \sigma} \quad (18)$$

Respectively, where $\sigma > 0, \zeta > 0, K > 0$.

Note that from simple manipulation, $C(s)$ in Figure 1 is equivalent to (9).

4. Conclusion

In this paper, we propose a design method for the control system with actuator failure detection using the extended semi-strongly stabilizing controllers with a pole at the origin and two pairs of poles on the imaginary axis. This result makes it possible to construct a system that can detect failure detection for actuator failures.

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Biographies

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