Responses to Dr. Tamás Péni as dissertation reviewer

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First, I would like to thank Dr. Tamás Péni for his attention, time, and effort in reviewing my dissertation titled *Model based fault diagnosis in networked linear time invariant systems.* Even though his comments, suggestions, and questions during my home defence were hard, they have been helpful in enhancing the quality of my dissertation. With his help, I could add an explanation about how to generalize my method to a broader class of problems.

Then, in the following, I provide my responses to his comments and questions related to my dissertation's final version for my final defence.

Comments / Questions 1

"In Chapter 3 that is about sensor and actuator fault diagnosis in robot or vehicle platoons, if both the sensor fault isolation filter and actuator fault estimator are applied on the same vehicle platoon, is it possible to detect one actuator and one sensor fault simultaneously or do we still have to assume only one fault occur at a time?"

Answer:

Further investigations are needed to answer this question. This has also been stated in the Future works in Section 6.2. in the dissertation.

However, we hypothesize the following:

Case 1: There are sensor faults when applying the proposed actuator fault estimator method.

The proposed actuator fault estimator design is built based on the following system model:

$$\begin{aligned} \dot{\boldsymbol{x}}^{(j)} &= \bar{A}^{(j)}\boldsymbol{x}^{(j)} + \bar{B}^{(j)}\boldsymbol{u}^{(j)} + \bar{L}^{(j)}\boldsymbol{x}^{(j-1)} + \bar{F}^{(j)}\boldsymbol{f_a}^{(j)} \\ \boldsymbol{y}^{(j)} &= \bar{C}^{(j)}\boldsymbol{x}^{(j)} + \bar{D}^{(j)}\boldsymbol{u}^{(j)} + \bar{E}^{(j)}\boldsymbol{x}^{(j-1)} \end{aligned} \tag{1}$$

where $\boldsymbol{x}^{(j)}$ is the states, $\boldsymbol{u}^{(j)}$ is the control input, $\boldsymbol{y}$ is the output, $\boldsymbol{f_a}^{(j)}$ is the actuator fault, and $\boldsymbol{x}^{(j-1)}$ is the neighbour's output.

Eq (1) shows that no sensor faults are considered in the system output $\boldsymbol{y}^{(j)}$. Moreover, $\boldsymbol{y}^{(j)}$ also depends on the neighbour's output $\boldsymbol{x}^{(j-1)}$ which can be affected by sensor fault from that neighbour. Thus, it can be concluded that the proposed actuator fault estimator method can be implemented when there are sensor faults only under severe assumptions: highly redundant measurements, and further assumptions on the $\bar{E}^{(j)}$ matrix.

Case 2: There are actuator faults when applying the proposed sensor fault isolation method.

Consider a general system model with sensor fault vector $\boldsymbol{f_s}$ and actuator fault vector $\boldsymbol{f_a}$ as follows:

$$\begin{aligned} \dot{\boldsymbol{x}} &= A\boldsymbol{x} + B(\boldsymbol{u} + \boldsymbol{f_a}) + E\boldsymbol{d} \\ \boldsymbol{y} &= C\boldsymbol{x} + \boldsymbol{f_s} \end{aligned} \tag{2}$$

where $\boldsymbol{x}$ is the state vector, $\boldsymbol{u}$ is the control input, $\boldsymbol{y}$ is the output, and $\boldsymbol{d}$ represents the disturbance.

The proposed sensor fault isolation method is built based on the theory of Unknown Input Observer (UIO). This UIO tries to decouple the disturbance $\boldsymbol{d}$ for system in Eq (2) so that the state estimation error $\boldsymbol{e}$ and the residual signal $\boldsymbol{r}$ are as follows:

$$\begin{aligned} \dot{\boldsymbol{e}} &= (A_1 - K_1 C)\boldsymbol{e} + TB\boldsymbol{f_a} - K_1\boldsymbol{f_s} - H\dot{\boldsymbol{f}}_{\boldsymbol{s}} \\ \boldsymbol{r} &= C\boldsymbol{e} + \boldsymbol{f_s} \end{aligned} \tag{3}$$

where A_1, K_1, T, and H are the UIO's matrices calculated to satisfy the observability conditions.

Eq (3) shows that $\boldsymbol{r}$ is affected by $\boldsymbol{f_a}$ and $\boldsymbol{f_s}$ simultaneously when both of them are not zero ($\boldsymbol{f_a}, \boldsymbol{f_s} \neq 0$). In other words, UIO can only isolate one of the sensor faults or actuator faults at a time. Thus, the proposed sensor fault isolation method can hardly be implemented when the actuator fault influences the corresponding sensor.

Comments / Questions 2

"In Chapter 5 that is about additive fault diagnosis in heat exchanger network, how restrictive are assumptions A1 - A4 in a real system?"

The assumptions A1 - A4 in the dissertation are as follows:

- A1 Only the transport of a single conserved extensive quantity (in this study, it is energy) is considered in the process systems. Thus, we have either energy-transport or mass-transport systems. Heat exchanger networks and domestic heating/cooling systems belong to the linear energy-transport class.

- A2 Only linear convection and transfer is considered without any linear source.

- A3 Constant overall mass and constant physicochemical parameters (such as density, specific heat, heat transfer coefficient, and convective flow rate) are assumed.

- A4 One inlet and one outlet flow are considered where the inputs of the systems are the intensive variable (temperature or concentration) at the inlet and that of the balance volume with which transfer is assumed. Meanwhile, the output is the intensive variable (temperature or concentration) at the outlet.

Answer:

Assumptions A1 and A2 generally hold for both industrial and domestic heating/cooling systems. Assumption A3 holds only if the state variables (the temperatures) do not vary over a wide domain, i.e. they only change by approximately a maximum of 10 degrees Celsius. This almost always holds for domestic heating/cooling systems but not for industrial ones. In the latter case, the heat transfer coefficient may depend on the temperature difference. The density and the specific heat may depend on the temperature. And, the flow rate may depend on the spatial position. These may make the model nonlinear. Assumption A4 also holds generally for one-sided common designs of both industrial and domestic heating/cooling systems.

Comments / Questions 3

"If all of those assumptions do not hold (or not all of them hold), can we simply skip the isolation part and run as many fault estimator filters in parallel as many fault locations are possible?"

Answer:

In this work, in Section 5.5. about fault observer design, a fault isolation method is proposed that can be applied by using only two sensors because it is considered that the number of available sensors is limited. Thus, as compensation, an iteration process is needed to specifically isolate the fault before estimating it. However, if an abundant number of sensors is assumed to be available, then the isolation part can be skipped to estimate the faults simultaneously (in parallel).

Veszprem, 2 May 2024

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