Identifying Faults: A Closed-loop Perspective

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Industrial Challenge

Problem:
- Downtime of production equipment $\rightarrow$ Very expensive!
- Motivates demand for:
  - Fault detection and Isolation (FDI) $\rightarrow$ Similarities to SysID
  - Fault tolerant control
  - Predictive maintenance
- Mechatronics:
  - Closed loop
  - Multivariate

Fault Diagnosis via Residual Generation

Goal:
- Q := $[Q_r \ Q_u]$ s.t.
  - setpoint decoupling ($G_{sr} = 0$)
  - fault sensitivity ($G_{sf} \neq 0$)
  - disturbance attenuation ($G_{sd} \approx 0$)

Specifically, maximize performance measure $\beta$ through

$$\beta = \max \left\{ \|G_{sf}\|_{\infty}, \|G_{sd}\|_{\infty} \leq \gamma \right\}$$

- Often claimed that feedback controllers do not affect FDI system design, see, e.g., [2, 3]
- Hence, the open-loop problem (\wedge) equals the closed-loop problem $\rightarrow$ Recall closed-loop identification problem?

Closed-loop MIMO perspective

In addition, from a MIMO perspective, caution is required!

- Naive indirect identification approach, e.g., $\hat{G}_s(e^{i\omega}) = \frac{\hat{G}_s(e^{i\omega})}{\hat{S}(e^{i\omega})}$ gives an estimate of $G_{sr,11} := G_{sr,11} - \sum_{k=2}^{n} G_{sr,21} C_{12}$ and results in bias due to cross-coupling $\rightarrow$ Matrix product for bias-free full plant, i.e., $\hat{G}_s(e^{i\omega}) = \hat{G}_s S(e^{i\omega}) S(e^{i\omega})^{-1}$
- Bias in estimation propagates to FDI design, severely compromising resulting filter!

Take home message 1:
- For FDI system design, indeed,
  - residual generation problem is invariant to controller $C$
  - Theorem: open-loop problem (\wedge) with $G_{sr} = 0$ is equivalent to closed-loop problem with $G_{sr} = 0$
  - I.e., the same filter $Q$ results, see [6] for details, confirming the implicit statements in [2, 3]

Discussion & Future Work

- Close link between SysID and fault identification $\rightarrow$ What can we learn?
- System reconfiguration, e.g., actuator force redistribution to counteract fault
- Predictive capability

References