

**Industrial Challenge**

Problem:
- Downtime of production equipment → Very expensive!
- Motivates demand for:
  - Fault detection and Isolation (FDI) → Similarities to SysID
  - Fault tolerant control
  - Predictive maintenance

Mechatronics:
- Closed loop
- Multivariate

**Fault Diagnosis via Residual Generation**

Goal: Design \( Q := [q_y, q_u] \) s.t.
- setpoint decoupling \( (G_{r,r} = 0) \)
- fault sensitivity \( (G_{f,f} \neq 0) \)
- disturbance attenuation \( (G_{d,d} \approx 0) \)

Specifically, maximize performance measure \( \beta \) through

\[
\beta = \max \left\{ \|G_{r,f}\|_\infty = \|G_{d,d}\|_\infty \leq \gamma \right\}
\]

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

**Closed-loop Noise perspective**

For identification, caution is required! E.g.,
- Spectral analysis \( \hat{G}_d(e^{j\omega}) = \frac{\Phi_{u1}(\omega)}{\Phi_{u1}(\omega)} = \frac{u_d(e^{j\omega}r_{12}(\omega)) - C \Delta e^{j\omega}r_{12}(\omega)}{\Phi_{e(e^{j\omega})}} \Phi_{u1}(\omega) \)
  - can result in bias due to correlation \( v \) and \( u \)
  - \( \rightarrow \) SysID solutions known [4] [5]

- Knowing whether controllers are in the loop is crucial!

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

**Closed-loop MIMO perspective**

In addition, from a MIMO perspective, caution is required!
- Naive indirect identification approach, e.g., \( \hat{G}_d(e^{j\omega}) = \frac{u_d(e^{j\omega})}{\Delta e^{j\omega}} \) gives an estimate of \( G_{r,r} := G_{r,r} - \sum_{i=1}^{2} \epsilon_{r,i} G_{r,i} e^{j\omega} \) and results in bias due to cross-coupling → Matrix product for bias-free full plant, i.e., \( \hat{G}_d(e^{j\omega}) = \hat{G}_d S(e^{j\omega}) S(e^{j\omega})^{-1} \)
- Bias in estimation propagates to FDI design, severely compromising resulting filter!

**Take home message 2:**
- Two design options:
  - Identify complete MIMO plant (if possible) and MIMO \( Q \) → gives \( C \) invariance
  - Identify equivalent plant to design \( Q \) → depends on \( C \) (e.g., if limited \( i/o \))

**Discussion & Future Work**

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

**References**