Physics-Based Methods for Distinguishing Attacks from Faults

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Outline

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Motivation

1. Cyber-Physical Systems (CPSs) are of great interest due to the wide application area where their model can be used.
2. System security and attacks detection can be studied through CPS models.
3. **Goal**: Detect and distinguish attacks from faults on a complex system using CPS models.

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1. Method for distinguishing attacks from faults on an observed-based framework.
2. Physics-based methods can be effective, but they cannot deal with every kind of attacks on the system.
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Preliminaries

- We assume that a CPS model is an instance of a hybrid system which can operate on different behaviours, called modes.

$$Modes : \begin{cases} y_{m_1} = g_1(x) \\ ... \\ y_{m_i} = g_i(x) \end{cases}$$

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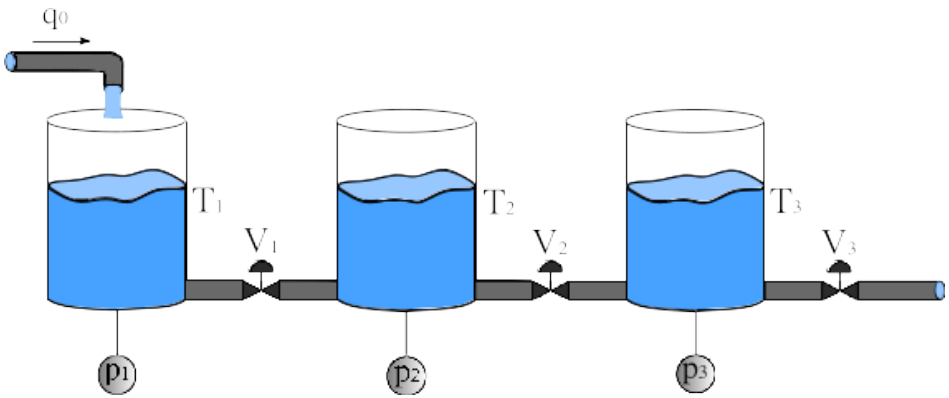
Nominal Model



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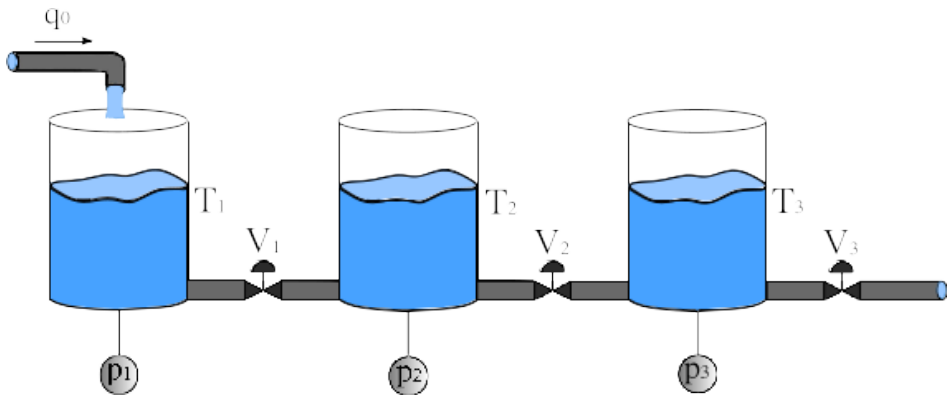

$$\frac{\delta h_1}{\delta t} = q_0 - q_1 = \frac{q_0 - k_1 sign(h_1, h_2)\sqrt{|h_1 - h_2|}}{A_1}$$

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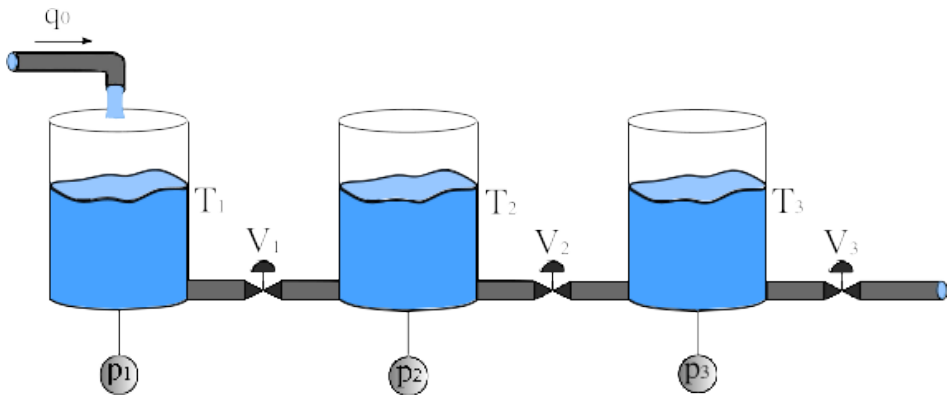

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Input: $u = \{q_0, v_1, v_2, v_3\}$ Output: $y = \{p_1, p_2, p_3\}$

Faults Model

- Valve faults, leaks, sensor faults, etc..
- Additive model:

$$v_i = \begin{cases} \max\{0, v_i + \Delta_{v_i}\}, & \text{if } \Delta_{v_i} \leq 0 \\ \min\{1, v_i + \Delta_{v_i}\}, & \text{if } \Delta_{v_i} > 0 \end{cases}$$

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Attacks Model

- The attacker cannot monitor the system, only data injection.
- **Sensor:** fake sensor reading in $[0, p_i^{max}]$
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Control Model

- Nominal system model:

$$\begin{aligned} x_{k+1} &= A_\gamma x_k + B_\gamma u_k + w_k \\ y_k &= C_\gamma x_k + v_k \end{aligned}$$

- Observer model:

$$\begin{aligned} \hat{x}_{k+1} &= A_\gamma \hat{x}_k + B_\gamma u_k + L_\gamma (y_k - C_\gamma \hat{x}_k) \\ \hat{y}_k &= C_\gamma \hat{x}_k + v_k \\ r_k &= y_k - C_\gamma \hat{x}_k \\ u_k &= -K_\gamma \hat{x}_k \end{aligned}$$

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External perturbation

- Faults influence:

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f_k and a_k are the fault and attack vector respectively.

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Fault or Attack

- Our system runs over different modes, each of which have a physical model ψ_i, creating the behaviour ξ_i having measurement $\hat{y}_i$.
- **Mode estimation:** closest mode to anomalous observation $\widetilde{y}_i$

$$\psi^* = arg \min_{\psi_i \in \Psi} ||\widetilde{y}_i - \hat{y}_i|| = arg \min_{\psi_i \in \Psi} r_i$$

- **Mode identifiability:**
  - distinguishable behaviour $\xi_i \ \forall j \neq i$
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Experiments

- Three types of tests:
  - Sensors attacks
  - Actuators attacks
  - Multiple components attacks
- Experiments environment:
  - Time domain: $[0, 50]$ seconds
  - Sensor data gathered every 2 seconds
  - Not faulty setting: $v_1 = v_2 = v_3 = 0.5$

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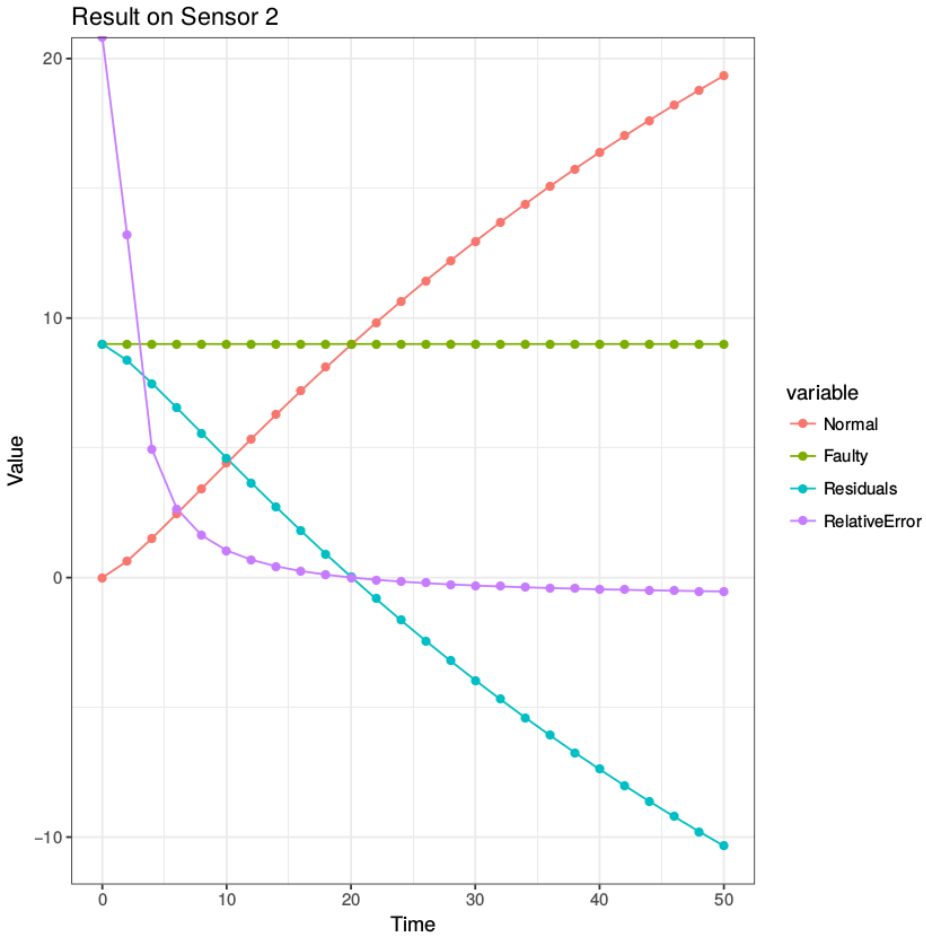
Attacks on Sensors

Injected data on the second sensor of our system

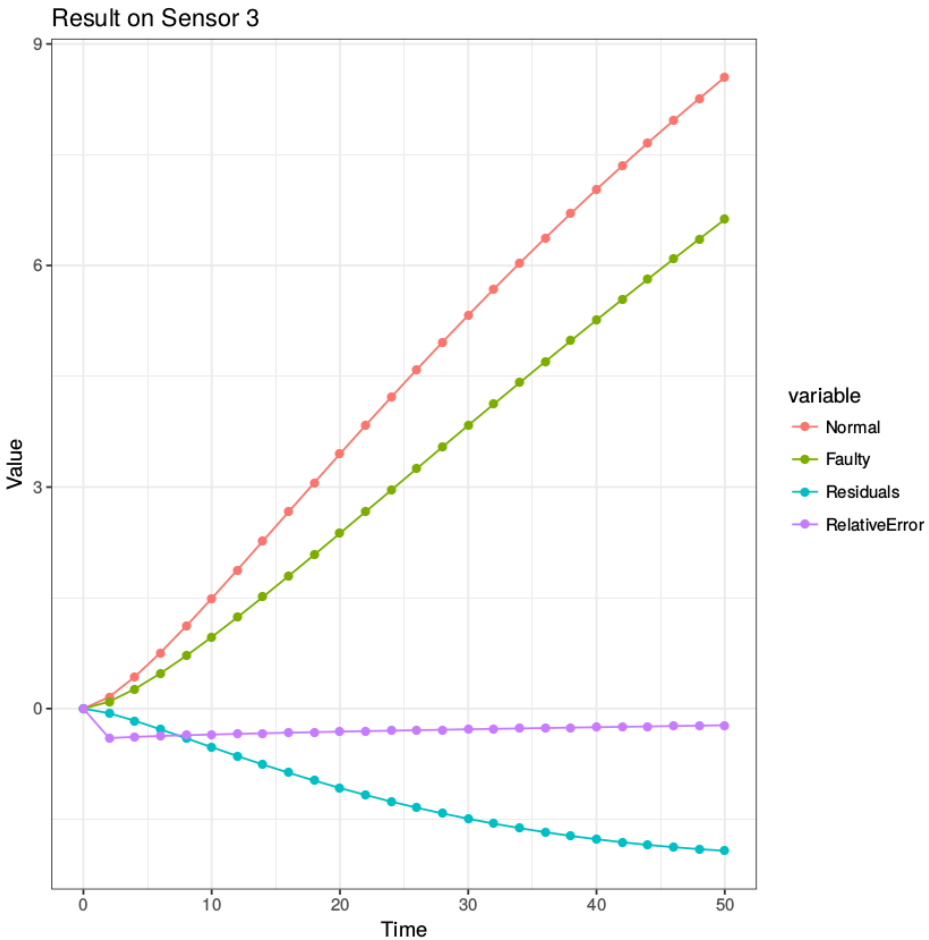


Attack identified through first derivative comparison:

$$\dot{y}_k = -\dot{r}_k$$

Attacks on Actuators

System complexity makes identifiability harder when the actuators are under attack, creating false positives.



Test	Valve 1	Valve 2	Valve 3
155	✓	X	X
355	✓	X	X
755	✓	X	X
955	✓	X	X
515	X	✓	X
535	X	✓	X
575	X	✓	X
595	X	✓	X
551			✓
553			✓
557			✓
559			✓
158	✓	X	✓
544	X	✓	✓
658	✓	X	✓
745	✓	✓	X
958	✓	X	✓
247	✓	✓	✓
638	✓	✓	✓

Multi Attacks and Results

Sensors problems correctly detected and identified.
Actuators errors detected.

Test	Valve 1	Valve 2	Valve 3	Sensor
s1_325		✓	X	1
s2_553	X		✓	2
s3_148	✓	✓		3
s12_558			✓	1-2
s23_647	✓			2-3
s31_348		✓		1-3
s123_666				1-2-3

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- Showed a security system approach based on Cyber-Physical Systems.
- Distinguishing attacks from faults is difficult when the system has a small number of sensors.
- Future work

  Deeper studies on the synergies of the system and between sensors data.

  Optimize the number of sensors in the system.

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