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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Contributions

1. Method for distinguishing attacks from faults in an observed-based framework.
2. Physics-based methods can be effective, but they cannot deal with every kind of attack.
3. Demonstrate approach on hydraulic benchmark system.

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Preliminaries

- CPS model is an instance of a hybrid system, which can operate in different behaviours, called modes.

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

- e.g. a drone has many operating modes
  - take-off, landing, wandering, surface mapping, ...
- The set of modes include also faults/attacks behaviour.

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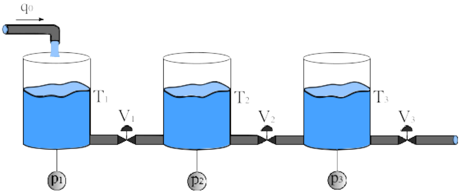

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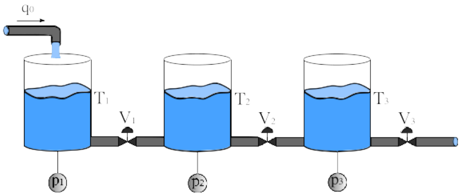

$$\frac{\delta h_1}{\delta t} = q_0 - q_1 = \frac{q_0 - k_1 sign(h_1, h_2)\sqrt{|h_1 - h_2|}}{A_1}$$

$$\frac{\delta h_2}{\delta t} = \frac{k_1 sign(h_1, h_2)\sqrt{|h_1 - h_2|} - k_2\sqrt{h_2}}{A_2}$$

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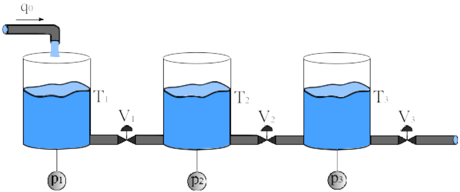

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Input: $u = \{q_0, v_1, v_2, v_3\}$ Output: $y = \{p_1, p_2, p_3\}$

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}
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- Observer model:

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\hat{x}_{k+1} &= A_\gamma \hat{x}_k + B_\gamma u_k + L_\gamma (y_k - C_\gamma \hat{x}_k) \\
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External perturbation

- Faults influence:

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

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f_k and a_k are the fault and attack vector respectively.

Fault Model

- Valve faults, leaks, sensor faults, etc..
- Valve setting: $V_i \in [0, 1]$
  - $V_i = 0$ is closed; $V_i = 1$ is open
- 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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- The attacker cannot monitor the system, only data injection.
- **Sensor:** fake sensor reading in $[0, p_i^{max}]$
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Fault or Attack

- Our system runs over different modes, each of which has 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
- Experimental environment:
  - Time domain: $[0, 50]$ seconds
  - Sensor data gathered every 2 seconds
  - Nominal setting: $v_1 = v_2 = v_3 = 0.5$

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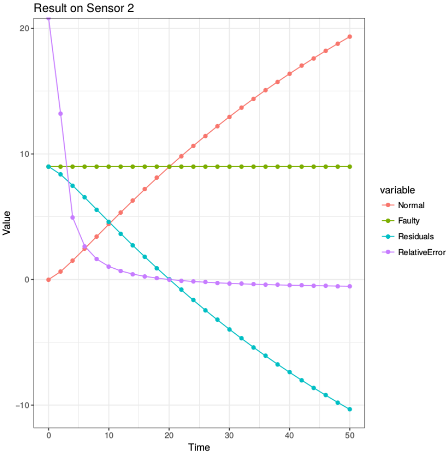
Attacks on Sensors

Injected data on the second sensor of our system

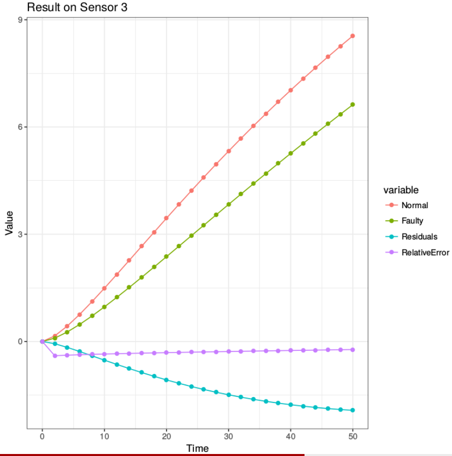


Attack identified through first derivative comparison:

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

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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Summary and Future Work

- Showed a security system approach based on Cyber-Physical Systems.
- Distinguishing attacks from faults is difficult when the system has few 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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Thank
You
Vinaka
köszönöm
Kiitos
Maake
Asante
Shukria
Dhanyavadagalu
감사합니다
Dankscheen
спасибо
Kam Sah Hammida
شكرا
Manana
Dankon
Diolch i Chi
Terima Kasih
Matondo
Dank Je
Mauruuru
Biyan
Taiku
Tack
Blagodaram
Ngiyabonga
Dziekuje
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Arigato
Grazie
Juspaxar
Mochchakkeram
Gracias
நன்றி
धन्यवाद
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cảm ơn bạn
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Paldies
Tingki
Gratias Tibi
Ua Tsaug Rau Koj
Dėkuji
Nirringrazzjak
Di Ou Mèsi
Kia Ora
Kop Khun
Obrigado
ありがとう
Suksama
Nuwun
Rahmat
Hvala
Welalin
Matur
谢谢
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Danke
Merci
Go Raibh Maith Agat
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Misaotra
Salamat
ขอบคุณ
Tuke
Najis