Evasion attack against Multivariate Singular Spectrum Analysis based IDS

Vikas Maurya, Rachit Agarwal, and Sandeep Shukla

Department of Computer Science and Engineering
Indian Institute of Technology Kanpur
Kanpur India

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Outline

- Industrial Control System
- Process-level IDS
- Attack Model
- MSSA based IDS
- Evasion attack
- Experiment and Result
- Conclusion

Industrial Control System (ICS)

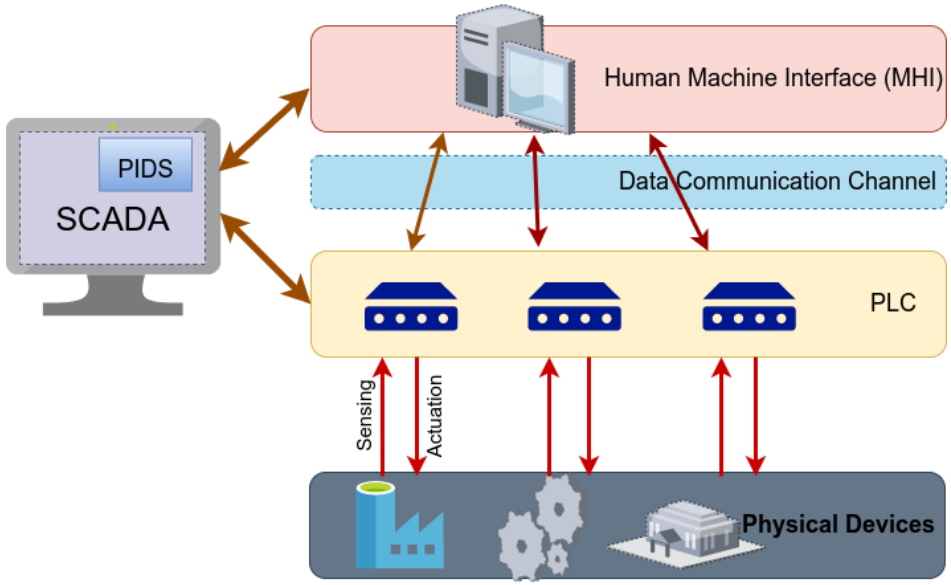


Figure 1: High level architecture of system model.

- CIs are mostly maintained by ICS
- Consists of various workstations
- Some past incidents are:
  - Iranian nuclear plant in 2009
  - German steel mill in 2014
  - Saudi petroleum refinery in 2017
  - Indian nuclear plant (NPCIL) in 2019
  - Israel water treatment plant in 2020

Process level IDS

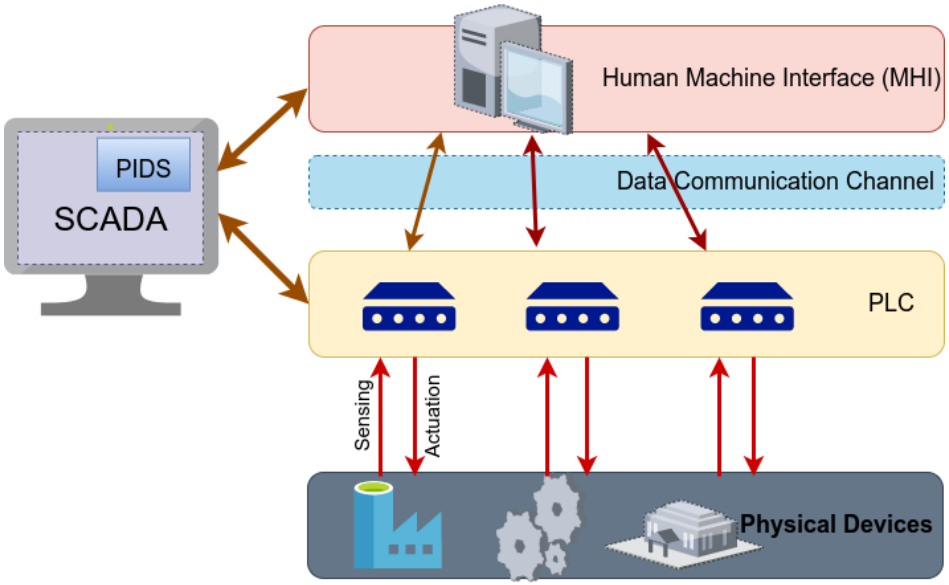


Figure 2: High level architecture of system model.

- An ICS is protected by various layers of protection
- But an attacker can evade such protection
- The ultimate attacker's aim gets reflected in physical process
- A process level IDS monitors the sensor measurements to detect attack induced abnormalities

Attack Model

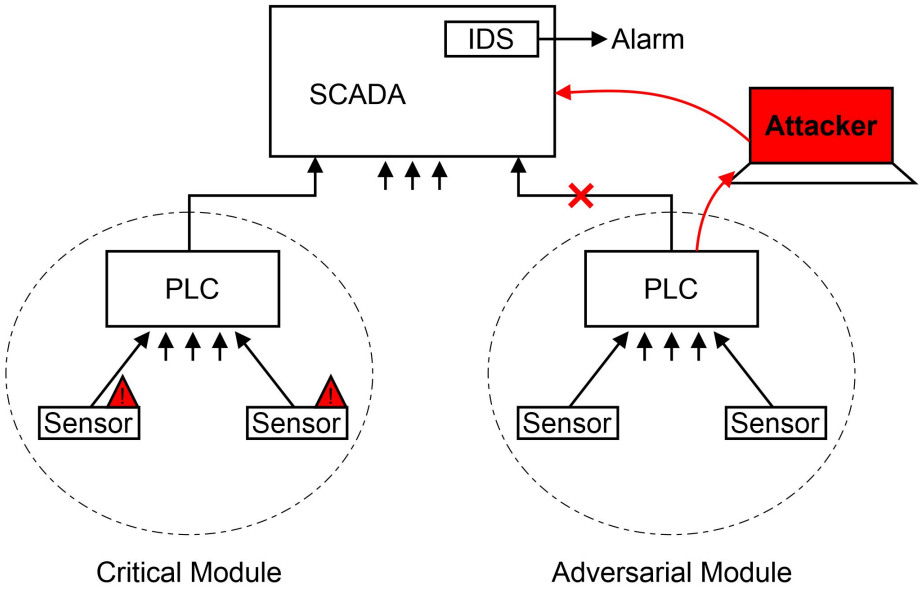


Figure 3: High level architecture of attack model.

- Attacker targets to the most critical component
- But the critical components are more protected
- Attacker finds some easy manipulable components
- A MITM attacker manipulate sensor measurements [1, 2, 3]
- Proposed perturbation method to craft adversarial measurements

MSSA based IDS

- A multivariate IDS
- MSSA based IDS [4] is:
  - Computationally efficient
  - Captures temporal information
  - Captures mutual correlation
  - Supports noise cancellation property
  - Capable to detect even a stealthy attack
  - Suitable for large scale ICS/IIoT networks

Working of MSSA based IDS

- It works by projecting the recent sensor measurements on noise free signal subspace
- Attack is detected based on departure of projected measurement

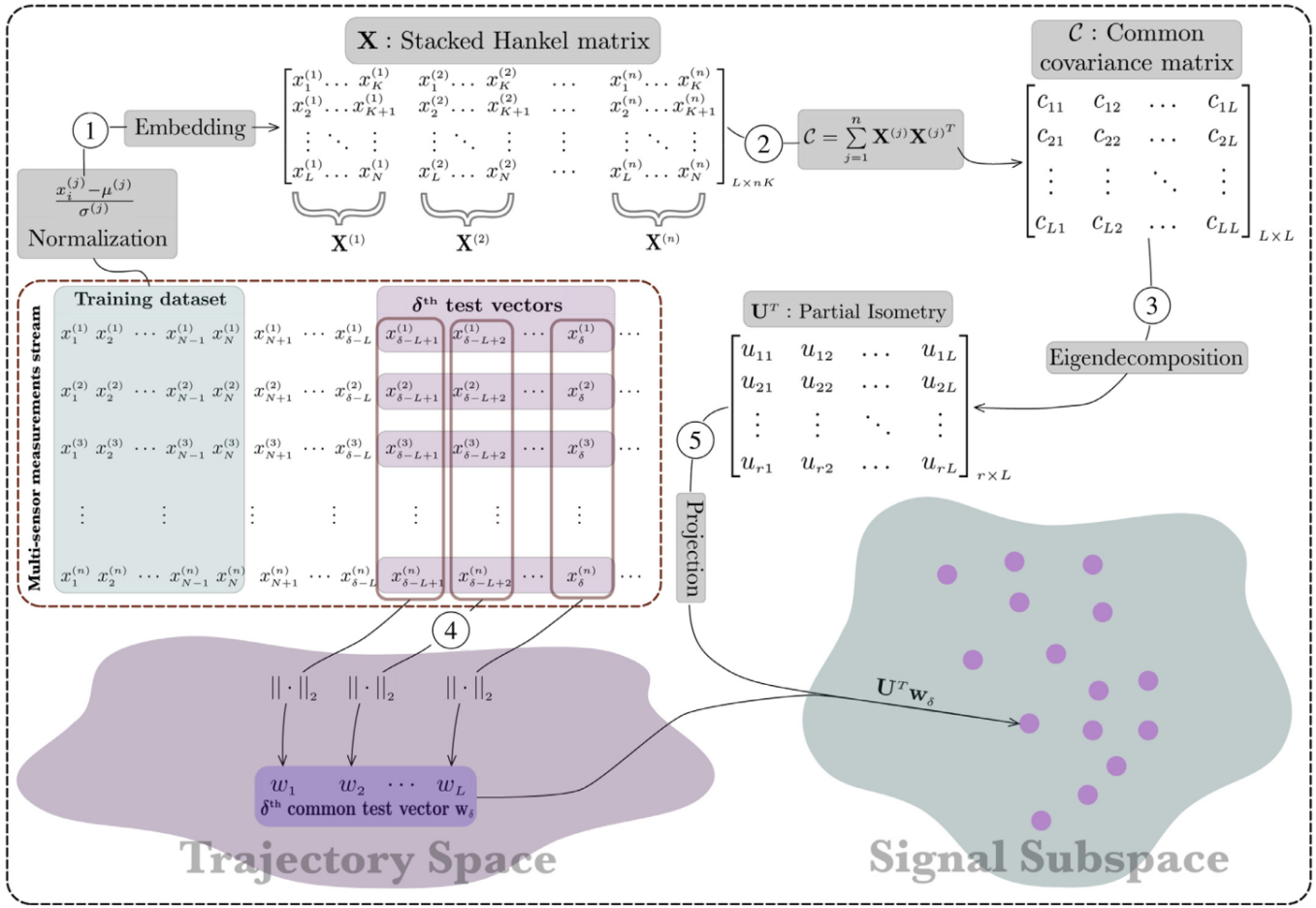


Figure 4: Working of MSSA Based IDS [4]

Model Parameters

- Parameters after training:
  - Projection Matrix: $U^T \in \mathbb{R}^{R \times L}$
  - Centroid Vector: $\hat{c} \in \mathbb{R}^R$
  - Classifier Threshold: θ
  - Lag Parameter L
  - $\mu^{(n)}$, $\sigma^{(n)}$

Online Detection

Consider an ICS consisting of N sensors where n^{th} sensor generates measurement $X_t^{(n)}$ at time t. The IDS performs following steps at timestamp t:

1. Normalization:
$$(X_t^{(n)} - \mu^{(n)})/\sigma^{(n)}$$
2. Compute aggregated measurement
$$m_t = ||X_t||$$
   - It forms an aggregated time series over time
$$\mathcal{T} = [\cdots, m_t, \cdots]$$
3. Compute L length lag vector:
$$w_t = [m_{t-L+1}, \cdots, m_{t-1}, m_t]^T$$
4. Compute the departure score:
$$D_t = ||\hat{c} - U^T w_t||^2$$
5. If $D_t > \theta$, then raise an attack alarm

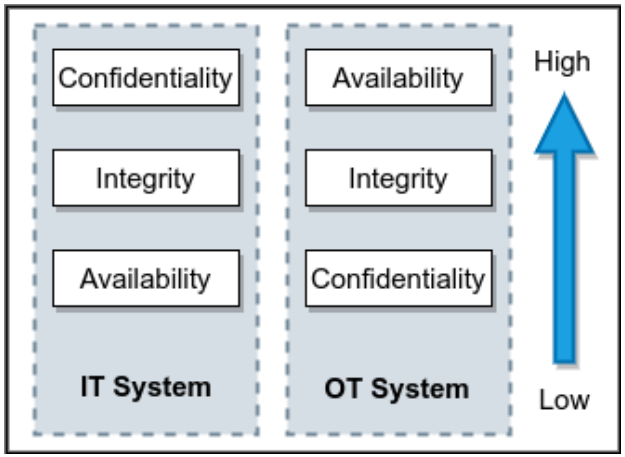
Related Works

- The current evasion attack methods [6, 7] are against deep-learning based IDS
- Do not consider time-series based models
- Deep-learning based IDS suffers from various limitations:
  - High computation cost
  - Noise cancellation property

The low computation cost and noise cancellation property of MSSA-based IDS make it one of the most suitable in large-scale ICS/IIoT networks, which motivates us to analyse it against evasion attacks.

Evasion Attack: Capabilities

- Accessibility



  - High availability supports non-encrypted communication [3, 5]
  - An attacker already present in the network can eavesdrop
- Manipulation capability
  - A rootkit can be deployed to PLC to manipulate the sensor measurements [1]
  - A victimized employee can be used for exploitation [2]
  - Various vulnerabilities are reported in OT networks, ≈83% violates communication [3]

Evasion Attack: Greedy Approach

- Objective Function:

$$\hat{m}_{t+1} = \arg\min_{m'_{t+1}} \left(D'_{t+1}\right)$$

- Simplify D'_{t+1} for unknown:

$$\begin{aligned} D'_{t+1} &= ||\hat{c} - U^T \cdot w'_{t+1}||^2 \\ &= ||\hat{c} - (U[1:L-1]^T \cdot w'_{t+1}[1:L-1] + U[L] * w'_{t+1}[L])||^2 \\ &= ||y - U[L] * m'_{t+1}||^2 \\ &= ||U[L]||^2 m'^2_{t+1} - 2(y^T \cdot U[L]) m'_{t+1} + ||y||^2 \end{aligned}$$

where,

$$y = \hat{c} - U[1:L-1]^T \cdot w'_{t+1}[1:L-1]$$

- Minima:

$$\hat{m}_{t+1} = \frac{y^T \cdot U[L]}{||U[L]||^2}$$

Evasion Attack: Reverse Engineering

- Estimate the adversarial measurements
  - Break $\hat{m}_{t+1} = ||X_{t+1}||$ into adversarial and non-adversarial:
    $$||X_{t+1}[\overline{adv}]||^2 + ||X_{t+1}[adv]||^2 = \hat{m}_{t+1}^2$$
  - Assumption $X_{t+1} \approx X_t$:
    $$||X_{t+1}[adv]||^2 = \hat{m}_{t+1}^2 - ||X_t[\overline{adv}]||^2$$
- Manipulation is performed only if departure score is above an estimated threshold

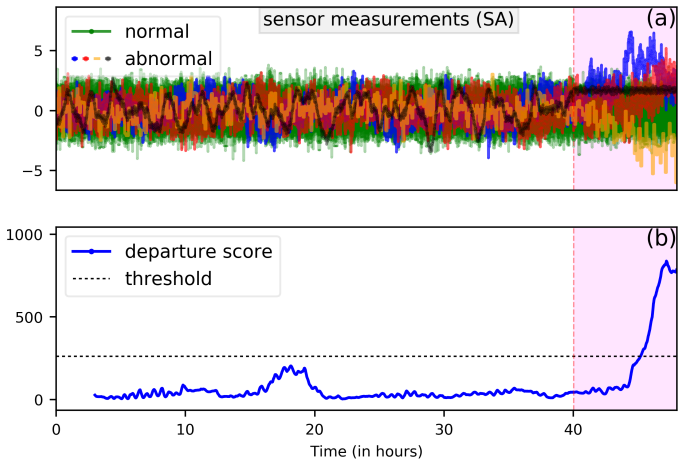
Evasion Attack: Constraints

- Accessibility constraints
  - White Box attacker: $(\mathcal{D}, \mathcal{X}, f, \phi)$
  - Gray Box attacker: $(\cancel{\mathcal{D}}, \mathcal{X}, f, \cancel{\phi})$
- Manipulation constraints
  - Manipulated measurement must be within the normal range

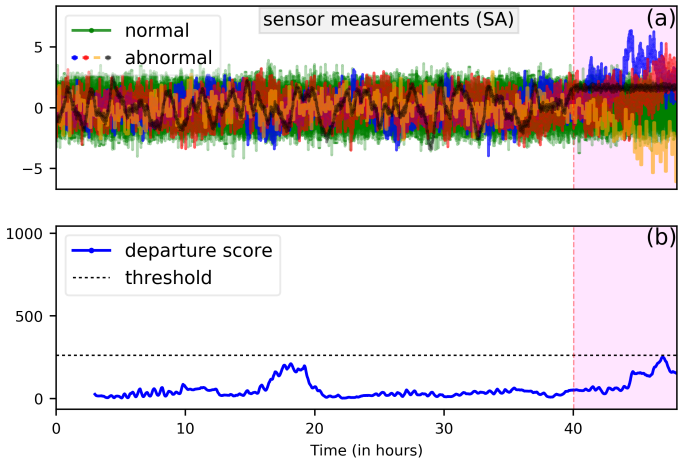
Data Preparation

- TE-process simulator [8] is used
- Generated normal measurements
- Generated stealthy attack dataset
- Generated Direct damage attack dataset
- Ensure main sensors impacted by attack

Stealthy attack scenarios

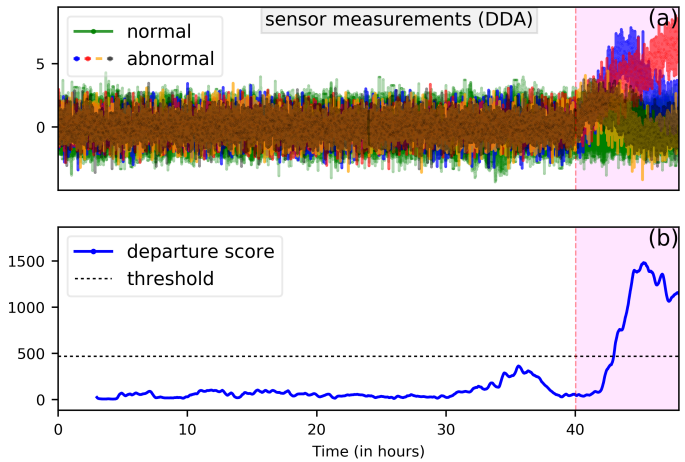


Before Manipulation

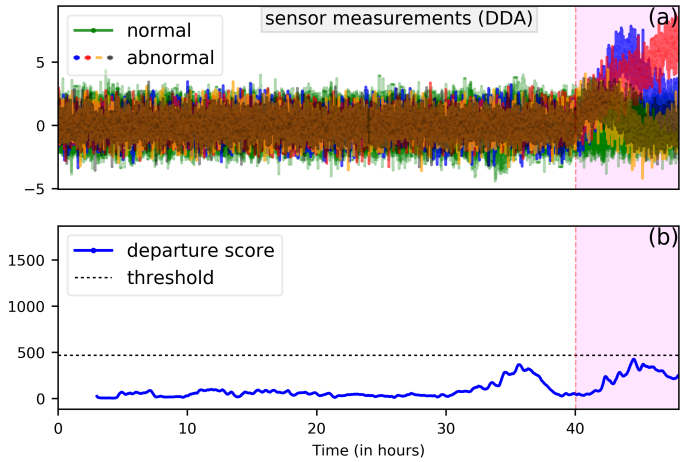


After Manipulation

Direct damage attack scenarios

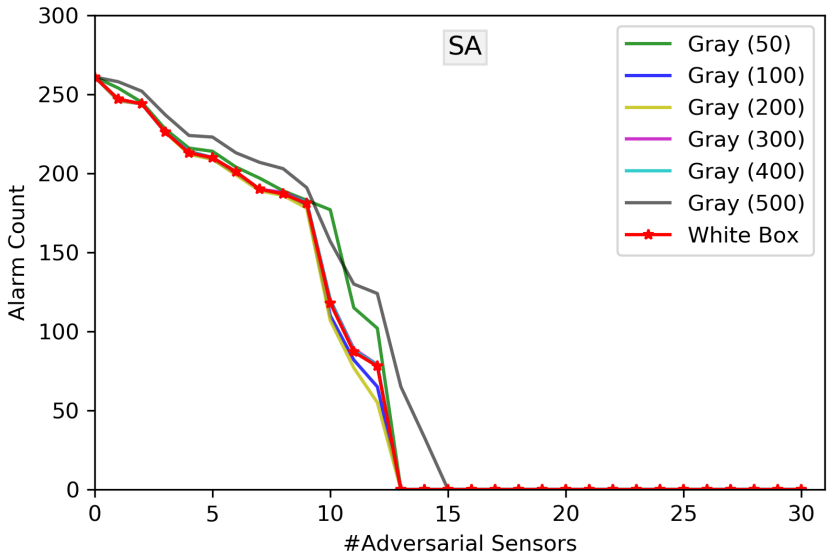


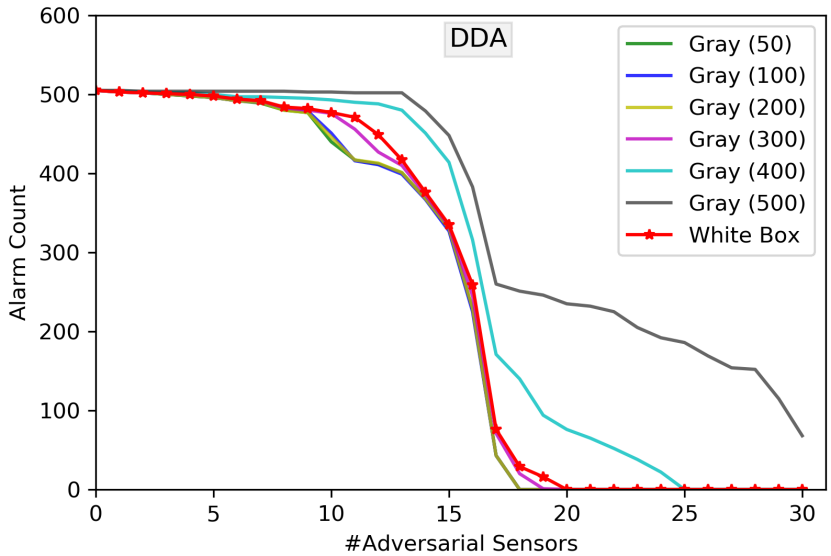
Before Manipulation



After Manipulation

White box and Gray box





Complexity Analysis

- Time Complexity: $O(RL)$
- Space Complexity: $O(RL)$
- Which is equal to the IDS
- Experimental: 53.7 μ-Sec

Conclusion

- We discussed vulnerability of MSSA based IDS
- A practicality of attack model
- Evasion attack against a time-series based IDS
- A novel perturbation method
- Demonstrated on SA and DDA attack scenarios

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Thank You!!