Knowledge Representation and Information Fusion Frameworks for Applications in Complex Cyber-Physical Systems

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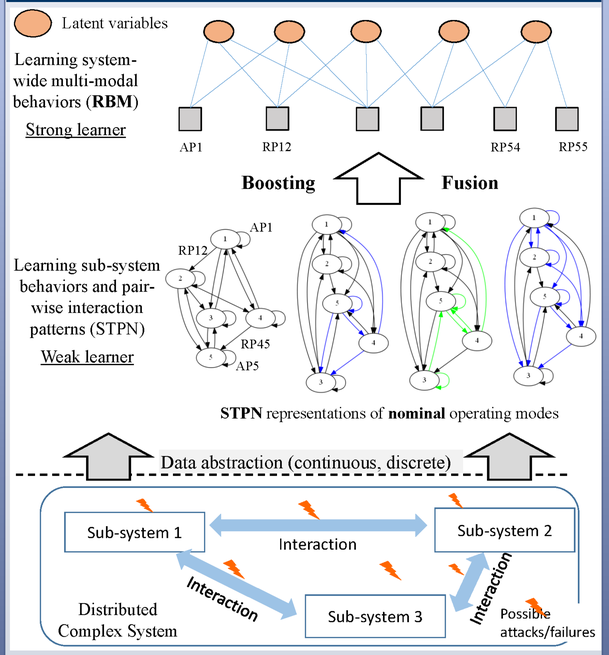
Project Objectives

- Develop a **data-driven modeling framework** for CPSs that reliably captures cyber and physical sub-system behaviors as well as their interaction characteristics.
- To address the need of **performance monitoring and fault detection & diagnostics** (FDD) in distributed CPSs (e.g., integrated building), with **cyber attacks and physical anomalies**.
- Applications: **Inference** and **root cause analysis** in complex CPSs, e.g., **bridge health monitoring, cyber-physical security for industrial robots, and non-intrusive load monitoring (NILM)**.

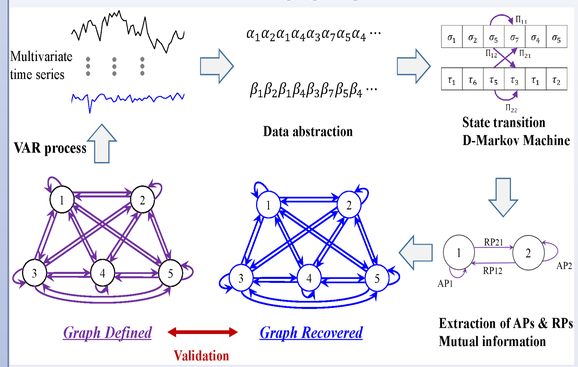
Previous work: Anomaly detection



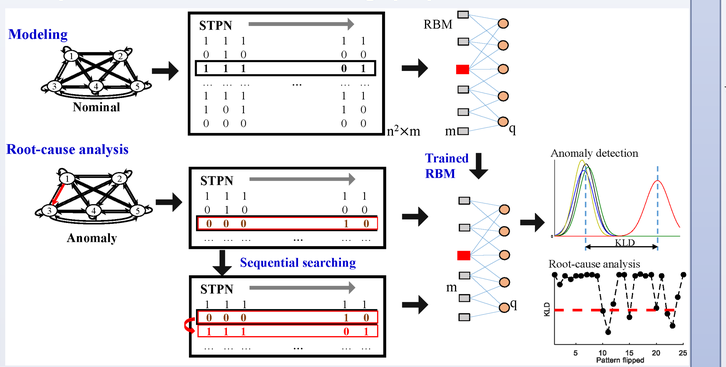
- A data-driven framework for **system-wide anomaly detection** was proposed, noted as the *STPN+RBM* model, to implement ***unsupervised*** anomaly detection with ***spatiotemporal causal graphical modeling***.
- Validation on synthetic data and real system shows the proposed framework can handle **mixed data types**, **local and global anomalies**, and capture **multiple nominal modes**.

Inference and Root-cause analysis via spatiotemporal causal graphical modeling

STPN for recovering graphical models

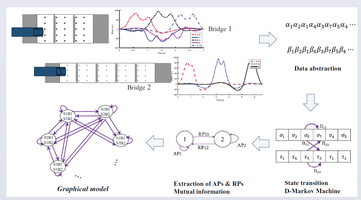


Sequential state switching (S^3)

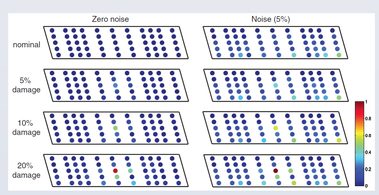


Case studies with bridges and industrial robots

Bridge damage detection using Dense Sensor Net (DSN)

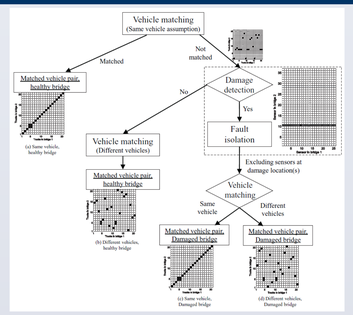


Vehicle identification



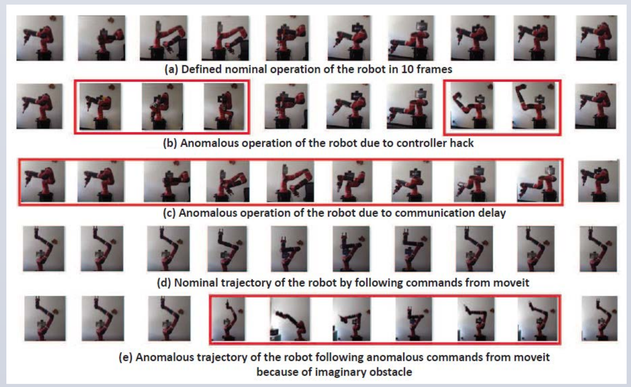
Damage detection

- A real-time decision-making framework for vehicle (load) identification, damage detection, and fault isolation



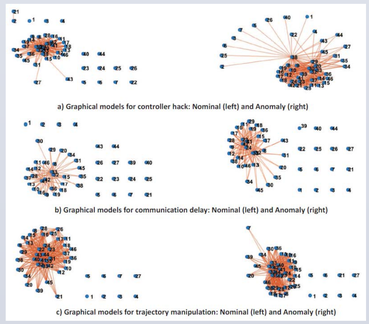
Decision-making

Detection and isolation of intelligent cyber-physical attacks on industrial robots

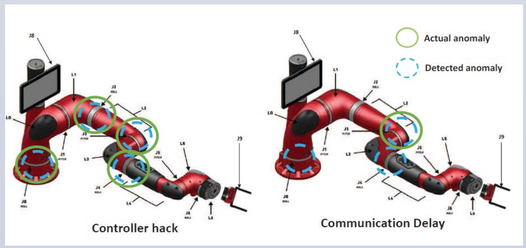


Time frames showing the task execution in nominal and anomalous conditions

- The proposed scheme is able to detect and isolate cyber-physical attacks reliably by running the various inference processes using streaming data.



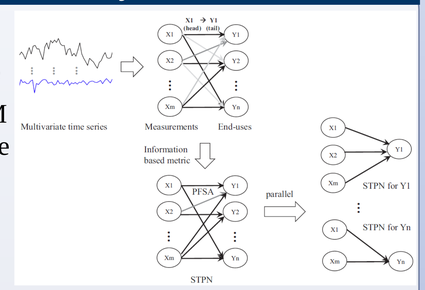
Derived graphical models with anomalies in the robot

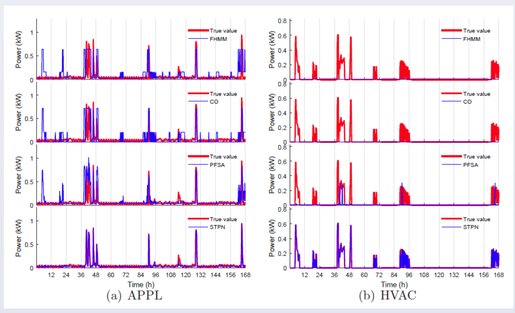


Actual and detected anomalies

Case study for NILM

Formulation of STPN for NILM with multivariate time series measurements





- Dataset: RBSAM
- STPN outperforms competitive methods, e.g., FHMM and CO

Conclusion & Publications

- A spatiotemporal graphical modeling technique is proposed for different CPS applications.
- Proposed approach demonstrated better or comparable performance than state-of-the-art.

Publications (selected)

- C. Liu, S. Ghosal, Z. Jiang and S. Sarkar, **An unsupervised anomaly detection approach using energy-based spatiotemporal graphical modeling**, *Cyber-Physical Systems*, 2017.
- Z. Jiang, C. Liu, A. Akintayo, G. Henze, S. Sarkar, **Energy Prediction using Spatiotemporal Pattern Networks**, *Applied Energy*, Volume 206, pp. 1022-1039, November 2017.
- C. Liu, Y. Gong, S. Laflamme, B. Phares and S. Sarkar, **Bridge damage detection using spatiotemporal patterns extracted from dense sensor network**, Measurement Science and Technology, Vol 61, No. 1, January 2017.
- C. Liu, K. G. Lore, S. Sarkar, **Data-driven root-cause analysis for distributed system anomalies**, *Proceedings of IEEE Conference on Decision and Control (CDC)*, (Melbourne, Australia), 2017.

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