A Reusable Framework for Fault Detection and Isolation in Small Satellites

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BACKGROUND

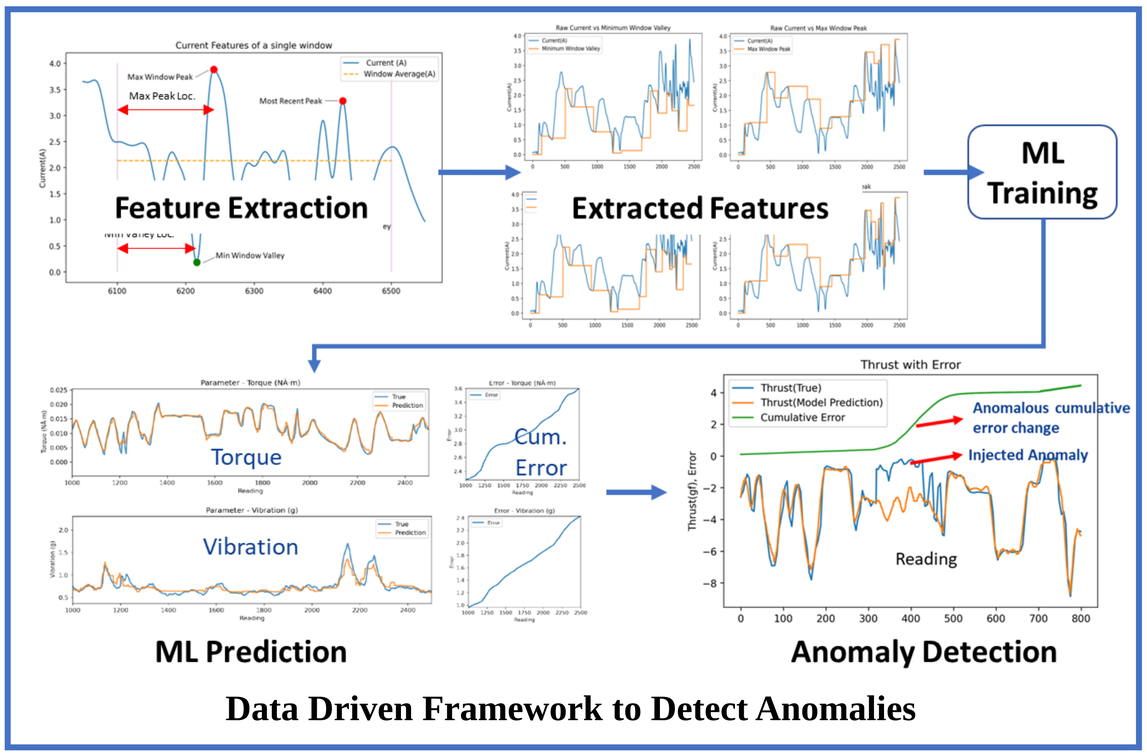
A. High failure rates: Nearly half of small satellites launched (2000-2016) experienced failures
B. Swift response vital: Detecting and addressing anomalies promptly enhances mission success
C. Cost constraints: Platform-specific solutions are expensive for small satellite teams
D. Need for adaptability: Reusable, data-driven framework adaptable to new platforms required
E. Comprehensive solution: Detect and isolate anomalous behaviors effectively

CHALLENGES IN CURRENT SOLUTIONS

A. Reusability limitations
B. Expertise requirements
C. Budget and timeline constraints
D. Testing and data generation needs
E. Explainability limitations
F. Insensitivity to subtle anomalies
G. Dependency on physics-based models

APPROACH

A. Data Collection: Gather non-anomalous data from the system or subsystem
B. Abstraction using Correlation Strengths: Use Dynamic Time Warping (DTW) technique to extract correlation strengths between system operational variables
C. Feature Extraction: Extract statistical features from a selected ground truth variable's time series data
D. Machine Learning (ML) Training: Train one-one ML models using the ground truth features to generate real-time estimates of expected nominal behavior
E. Anomaly Injection & Testing: Introduce various anomalies to test and optimize detection parameters
F. Anomaly Detection: Employ adaptive threshold-based unsupervised methods to identify sustained differences between ML predicted and observed behavior
G. Simultaneous Anomaly Isolation: One-to-one ML models simultaneously identify the anomalous operational variable



Data Driven Framework to Detect Anomalies

By following this approach, the proposed framework can rapidly detect and isolate anomalous behaviors in small satellite systems, without the limitations of current fault management solutions.

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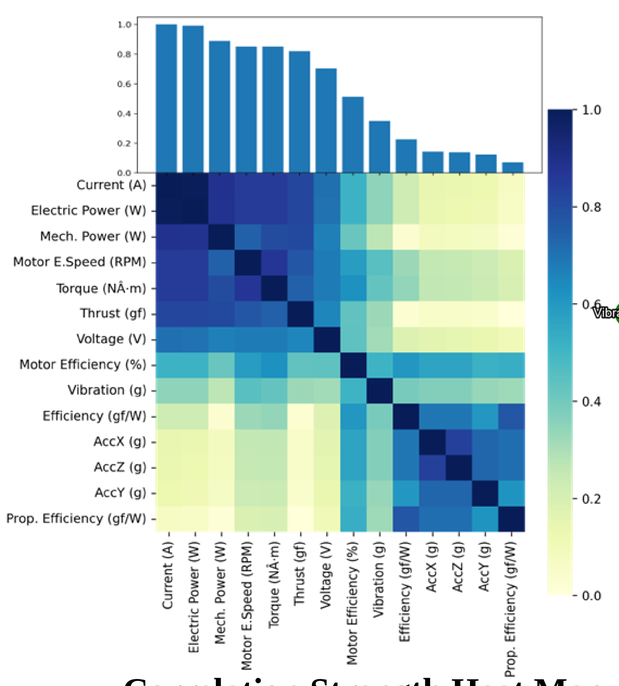
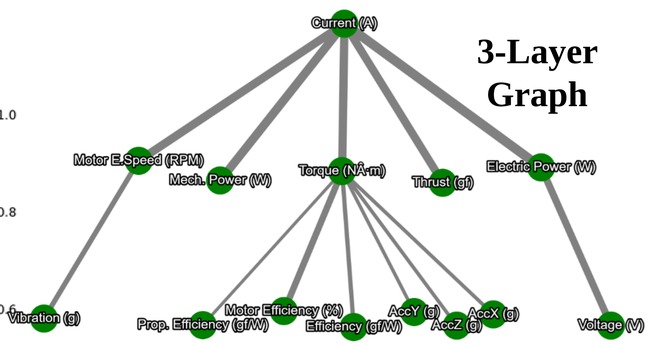
RESULTS

A. This framework is prototyped into algorithms and tested on several systems – electrical propulsion testbed, UAVs, and satellite testbeds
B. Results show many predictable operational variables and reliable anomaly detection on even very subtle anomalies

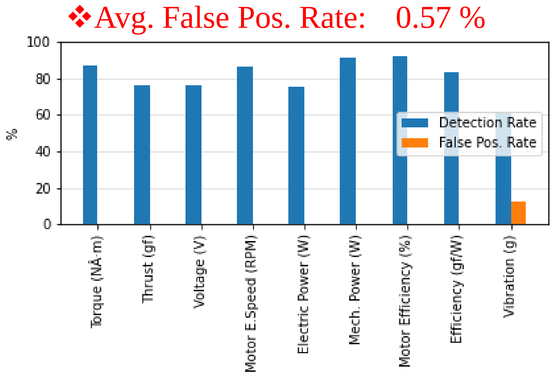
Abstraction and Anomaly Detection Results on El. Propulsion Testbed



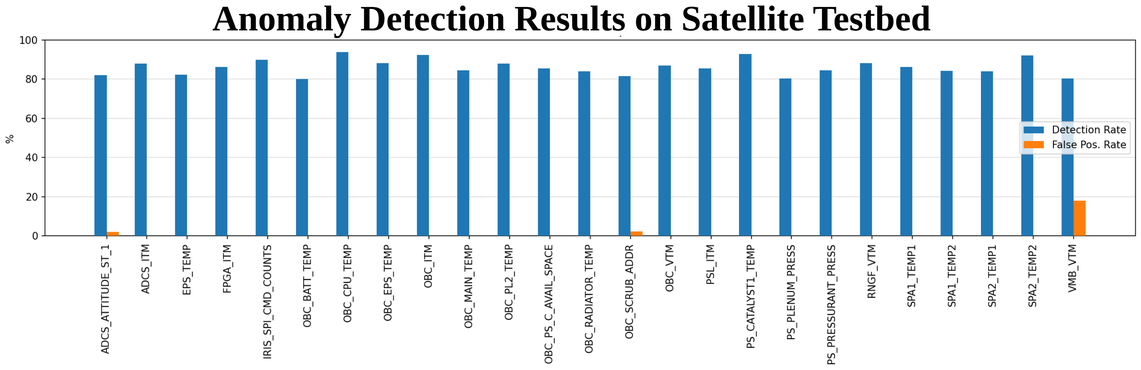
Correlation Strength Heat Map



❖**Avg. Detection Rate: 82.8 %**
❖Avg. False Pos. Rate: 0.57 %



Anomaly Detection Results on Satellite Testbed



❖**Avg. Detection Rate: 89.1 %** ❖Avg. False Pos. Rate: 0.89 %

CONCLUSIONS

A. A reusable and a data-driven framework is developed and tested
B. Shows great promise for onboard as well as ground-based monitoring operations
C. Applicable also for testing during mission development

FEATURES & BENEFITS

A. Cost effective and rapid fault management solution
B. Reduced mission development and operational costs
C. Ability to increase mission autonomy
D. Flexible computational overhead
E. Cyberphysical system security

FUTURE WORK

A. Evaluate the algorithms offline on operational data from a satellite
B. Deploy for ground-based monitoring of an operational satellite