Graph Neural Networks for Anomaly Detection in Controlled Mechanical Systems of Aircrafts

Context of the research

Electro-Mechanical Actuators (EMAs) are devices that convert electrical energy into mechanical motion. They are used in many industrial sectors, such as aerospace, automotive, robotics and manufacturing. This thesis work considers EMAs in aircraft flight control surfaces. They typically consists of a servo motor, a power inverter, mechanical components, such as a motor and a gearbox, a control unit and several sensors. Designed to maintain desired performance by adjusting variables to compensate for disturbances, EMAs can inherently mask the presence of anomalies, especially when they develop gradually. Consequently, the development of anomaly detection systems is fundamental for the early identification of anomalies in EMAs, preventing their potential escalation into severe malfunctions.

Key challenges to consider include:

- Adaptive compensation: control systems may mask anomalies by adjusting other variables and, therefore, complicating the identification of root causes.
- Gradual degradation: slowly evolving anomalies may go unnoticed until reaching a critical failure point.
- Disturbance rejection: many control systems treat anomalies as noise, filtering them out and thereby delaying detection.

In recent years, Graph Neural Networks (GNNs) have emerged as a powerful tool for anomaly detection. By representing systems as graphs, where nodes correspond to components and edges correspond to interactions, GNNs can model complex relationships, incorporate spatial and temporal dependencies, and adapt to changes in the system structure and behaviour.

Objective of the research

This research aims to develop a GNN-based methodology for anomaly detection in EMAs of new aircraft systems. The proposed approach will be benchmarked against state-of-the-art anomaly detection techniques to evaluate its effectiveness and identify potential advantages.

The research activities include:

- Conducting a literature review on anomaly detection in controlled systems and the application of GNNs.
- Developing a GNN-based framework for detecting anomalies.
- Implementing and evaluating state-of-the-art anomaly detection approaches for comparison.
- Applying the developed methodology to both synthetic and real scenarios.
- Analysing results to identify methodological strengths, limitations, and avenues for future research.
- Writing of scientific papers as chapters of the thesis.

Case study

Electro-Mechanical Actuators of New Aircrafts

In new aircraft system architectures, traditional hydraulic actuators of flight control systems are progressively replaced by EMAs, which offer multiple advantages in terms of modularity, mechanical simplicity, overall weight and fuel efficiency. The available dataset is composed of: *i*) data in normal conditions simulated by means of a high-fidelity model of an EMA, *ii*) experimental data obtained from a test bench, which closely resembles a real EMA architecture to simulate field data from aircraft flights for new-design systems.

Collaborations

The work will be performed at the Laboratory of Analysis of Systems for the Assessment of Reliability, Risk and Resilience (LASAR[3], www.lasar.polimi.it) of Politecnico di Milano in collaboration with the Department of Mechanical and Aerospace Engineering (DIMEAS) of Politecnico di Torino.

For further information, please contact:
Prof. Piero Baraldi, piero.baraldi@polimi.it, 02 2399 6345
Prof. Enrico Zio, enrico.zio@polimi.it, 02 2399 6340