Experimental Evaluation of Model-Free Neural Fault Detection and Identification in Quadrotors

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Can a neural network-based **model-free FDI framework** be implemented on a **Crazyflie quadcopter** with a motor failure?

Motivation

- UAV motor faults can lead to catastrophic crashes
- Traditional fault detection relies on accurate system models → performance drops under uncertainty
- Real-world systems face modeling errors, noise, actuator wear, and disturbances

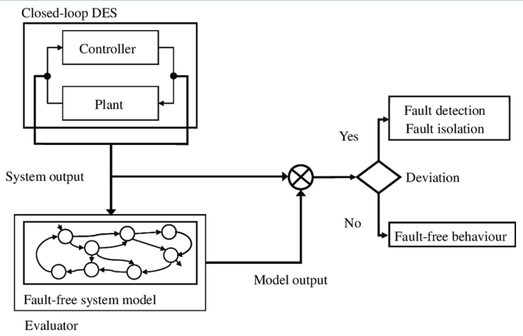

Figure 1- Model based FDI framework

Objectives

- Implement a model-free neural network-based FDI for quadrotors
- Leverage Dynamic Symmetry of the quadrotor to train the detector on a single-motor fault, achieving generalized fault prediction for all actuators.
- Deploy on Crazyflie UAV for real-time inference

Methodology

- Model-Free LSTM Fault Classifier:
  - Input: sliding window of outputs $y(t-\tau{:}\,t)$ +commands $u(t-\tau{:}\,t)$
  - Output: motor fault vector $\widehat{\Theta}$)partial to complete loss)
- Actuator Fault Representation

$$u(t) = diag(\Theta)\,\pi(t, x), \Theta_i \in [0, 1]$$

- Dynamic Symmetry Trick
  - Train on fault in one motor (#2)
  - Apply rotation transform $\Phi_n$to generalize to all motors
- Training Process
  - Sample initial states, roll out trajectories with random fault times
  - Store (y, u)windows in replay buffer
  - Train until loss $< 10^{-3}$or max iterations reached
- Loss function
  - Model-free learning loss:

$$L_{\Theta}^{MF} = \frac{1}{N}\sum(\parallel \Theta_{NN}(y, u) - \Theta \parallel - \epsilon)_{+}$$

Framework

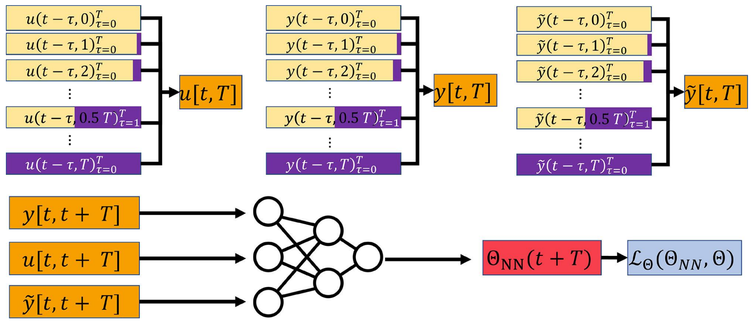

Figure 2- Model Free Neural network based FDI framework

Results

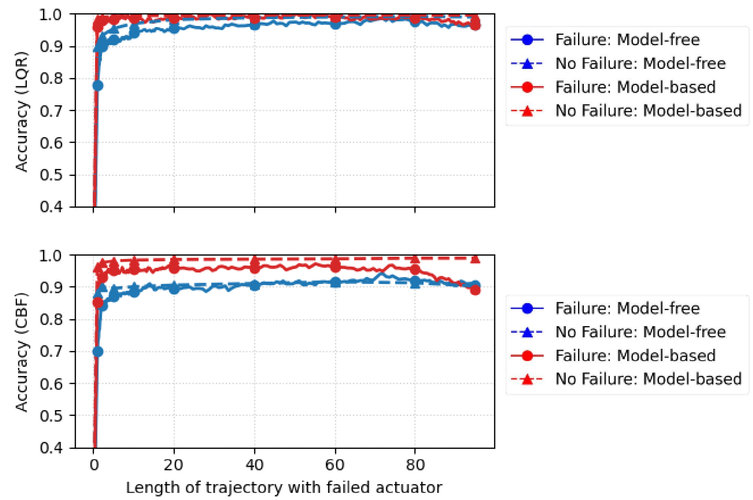

Figure 3: Failure prediction accuracy for CBF-QP input (solid lines) and LQR input (dashed lines). The performance of model-free (Ours) FDI with data (y, u) is shown in blue, while the one with all the data (y, u, ˜y) is in red.

Future Work

- Deploy the framework on the crazyfile UAV
- Create a safety mechanism for task completion after fault detection

References

- Garg, K., Dawson, C., Xu, K., Ornik, M., & Fan, C. (2023). *IEEE Control Systems Letters*.

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