**MOTIVATION**

- Emergence of safety-critical autonomous cyber-physical systems
- Increasing vulnerability to electro-mechanical performance degradation and failures
- A self-driving car failed about every 3 hours due to hardware or software malfunction

**PROBLEM STATEMENT**

Design self-aware autonomous systems that are resilient to electro-mechanical degradation, failures in sensors, actuators and control program

Need to address error detection, diagnosis and correction/compensation in real-time without expensive hardware and computation overhead

**PRELIMINARIES: STATE VARIABLE SYSTEM**

Plant – physical process to be controlled
Actuators/Sensors – Interface between digital and analog world
Controller – Running on digital processor core

\[ x = f(x,u) + w(t) \]
\[ y = h(x) + v(t) \]

- Introduce coding vector (CV), a row matrix
- \( M = CV.A,N = CV.B \)
- Multiply with \( CV \) and integrate
- Linear check, \( e(t) = M \int x(t) \, dt + N \int u(t) \, dt - CV.y(t) \)
- By design, \( e(t) = 0 \) in nominal system in nominal condition
- Practically, for noise and other modeling mismatches, \( e(t) \) is bounded
- Overhead is \( \frac{N}{2} \), since for \( n \) states, 1 extra state is being computed
- Any malfunction in plant/controller detected in real time

**TEST CASE (QUADCOPTER) AND EXPERIMENTAL RESULTS**

**STATE SPACE CHECKS FOR NONLINEAR SYSTEMS**

- Each column represents observable state measurements and inputs
- \( F_e \) is trained by nonlinear machine learning model
- \( F_p \) is computed by linear weighted sum of next states
- State space check is defined as: \( e(t) = v(t) - V(t) \)

**HIERARCHICAL CHECKS FOR NONLINEAR SYSTEMS**

General setup
Hierarchical check for quadcopter system

**REFERENCE**

- Boeing’s Crashes Expose Reliance on Sensors Vulnerable to Damage
- Related issues with Uber, Tesla, Google (Waymo) and Ford
- Sources:
  1. Boeing’s crashes expose reliance on sensors vulnerable to damage, 2019.
  3. Report: Tesla says fatal crash involved Autopilot, 2018