ROBUST AND RELIABLE ERROR DETECTION AND CORRECTION FOR AUTONOMOUS SYSTEMS

MD IMRAN MOMTAZ, ABHIJIT CHATTERJEE

ELECTRICAL AND COMPUTER ENGINEERING, GEORGIA INSTITUTE OF TECHNOLOGY, ATLANTA GA 30332

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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

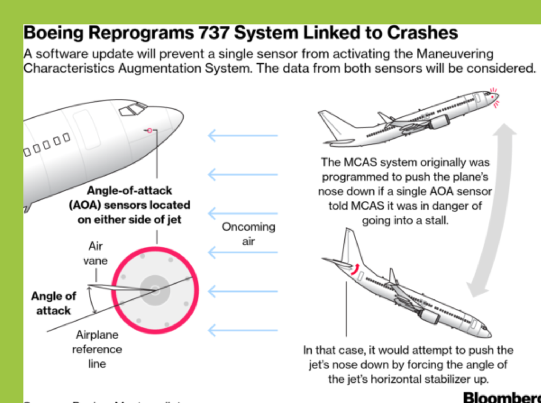
Company	Autonomous miles	Disengagements	Rate per 1000 miles
Google	635868	124	0.20
Cruise	10015	284	28.36
Nissan	4099	28	6.83
Delphi	3125	178	56.95
Bosch	983	1442	1466.94
Mercedes	673	336	498.95
BMW	638	1	1.57
Ford	590	3	5.08
Tesla	550	182	330.91
Honda	0	0	0.00
VW	0	0	0.00

2016 Autonomous vehicle disengagement data: California Department of Motor Vehicles

MOTIVATION

Boeing's Crashes Expose Reliance on Sensors Vulnerable to Damage
By Alan Levin and Ryan Beene | April 11, 2019

https://www.claimsjournal.com/news/international/2019/04/11/290347.htm



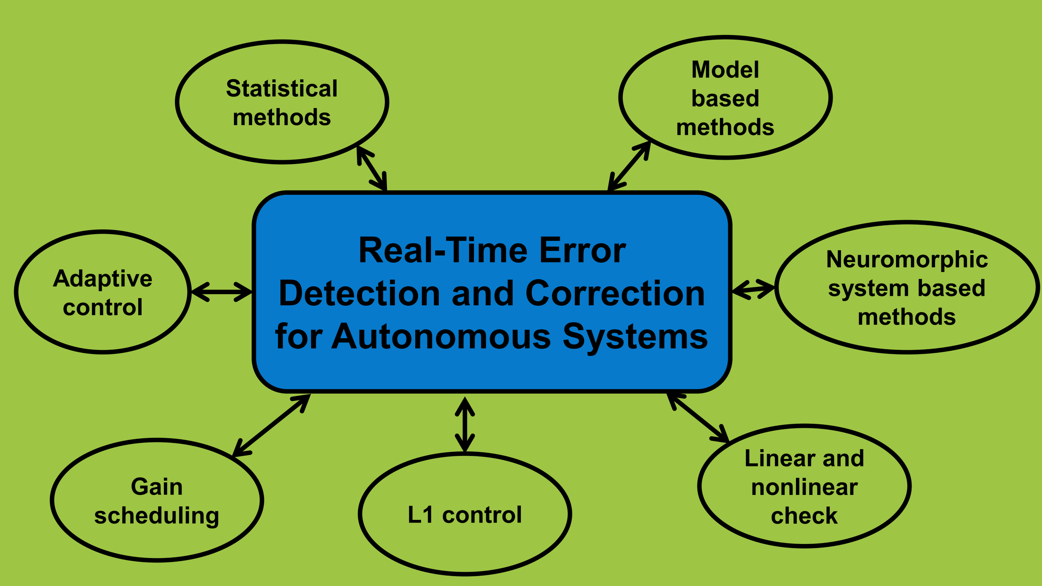
Related issues with Uber, Tesla, Google (Waymo) and Ford
Source:

[1] Boeing's crashes expose reliance on sensors vulnerable to damage, 2019.
[2] Report: Uber's self-driving car sensors ignored cyclist in fatal accident, 2018.
[3] Report: Tesla says fatal crash involved Autopilot, 2018
[4] Report: A Google self-driving car caused a crash for the first time, 2016.
[5] Report: Ford-backed self-driving car involved in an accident that sent two people to the hospital, 2018.

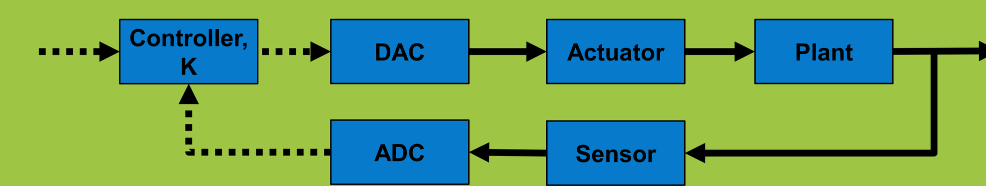
PROBLEM STATEMENT

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



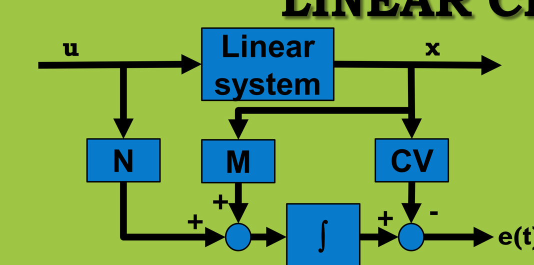
Plant – physical process to be controlled
Actuators/Sensors – Interface between digital and analog world
Controller – Running on digital processor core

$$\dot{x} = f(x,u) + w(t)$$
$$y = h(x) + v(t)$$

→ Analog signal
⋯→ Digital signal

$f(.)$ = System dynamics
$h(.)$ = Measurement model
$w(t), v(t)$ = Process and measurement noise (Zero mean gaussian)

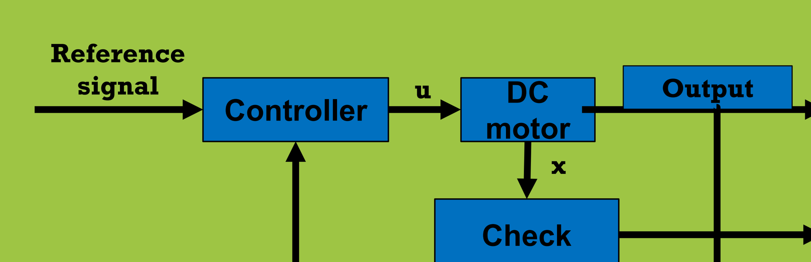
PRELIMINARIES: LINEAR STATE VARIABLE SYSTEM AND LINEAR CHECK



$$\dot{x} = Ax + Bu$$

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

TEST CASE AND EXPERIMENTAL RESULTS



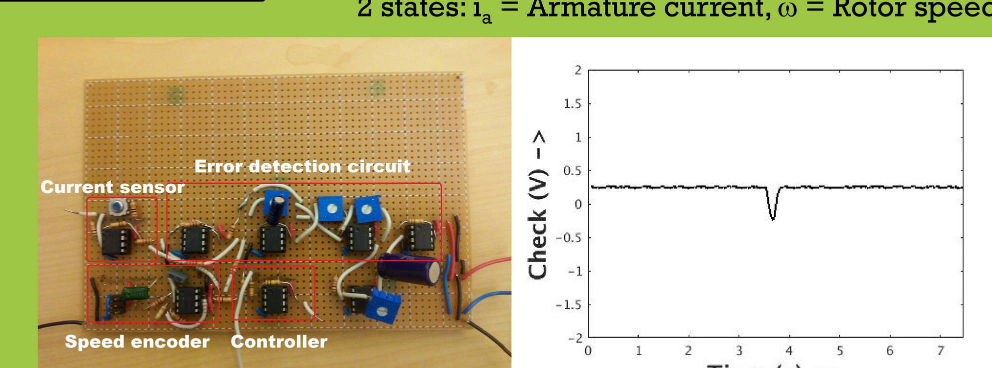
R_a = Armature resistance, L_a = Self-inductance, K_b = Back emf constant, K_e = Torque constant, J = Moment of inertia, B_1 = Co-efficient of viscous friction

2 states: i_a = Armature current, ω = Rotor speed

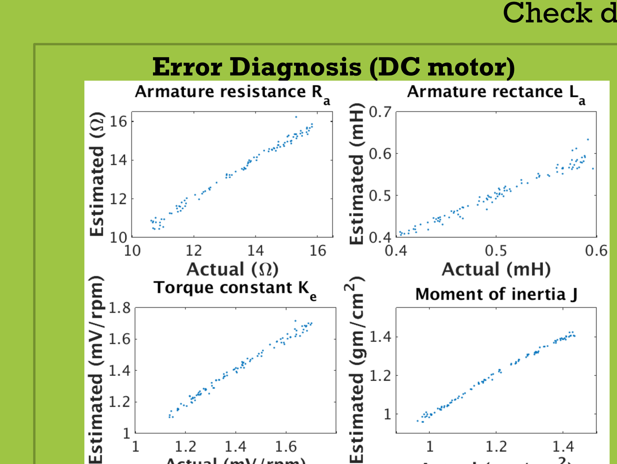
Governing equation

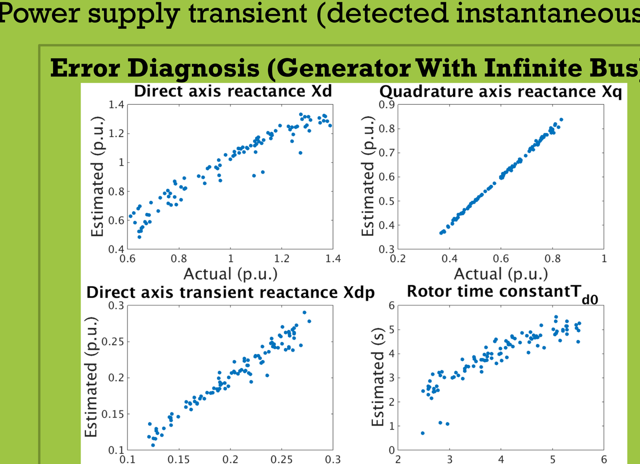
$$\dot{i}_a = -\frac{R_a}{L_a}i_a - \frac{K_b}{L_a}\omega + \frac{1}{L_a}V$$
$$\dot{\omega} = \frac{K_b}{J}i_a - \frac{B_1}{J}\omega - \frac{1}{J}T_L$$

Check, $e(t) = M\int x(t)\,dt + N\int u(t)\,dt - CV.x(t)$

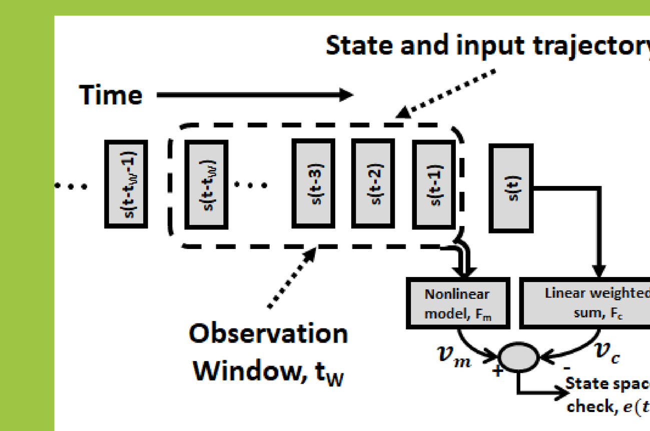


Check due to Power supply transient (detected instantaneously)





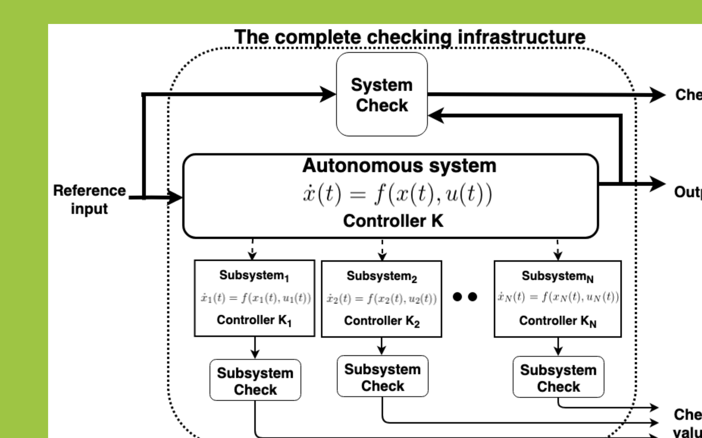
STATE SPACE CHECKS FOR NONLINEAR SYSTEMS



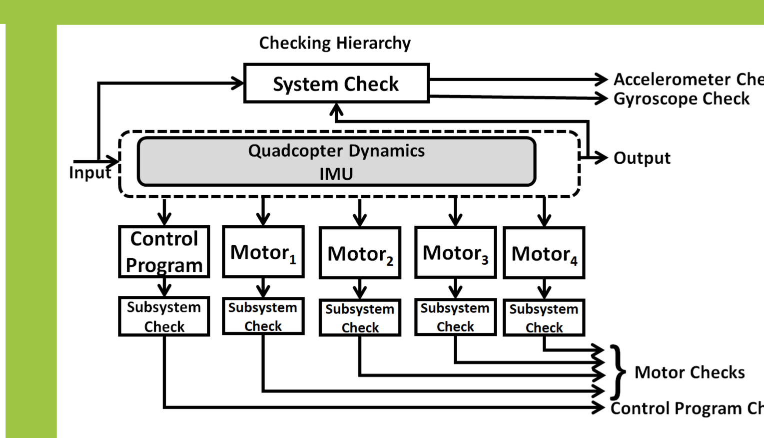
$$s(t) = \begin{bmatrix} y(t) \\ u(t) \end{bmatrix}$$

- Each column represents of observable state measurements and inputs
- F_m is trained by nonlinear machine learning model
- F_c is computed by linear weighted sum of next states
- State space check is defined as: $e(t) = v_m(t) - v_c(t)$

HIERARCHICAL CHECKS FOR NONLINEAR SYSTEMS

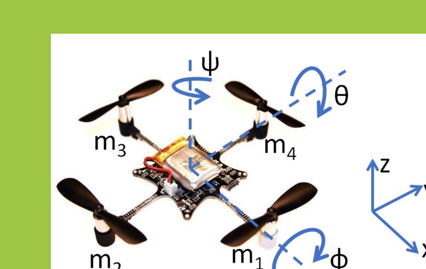


General setup

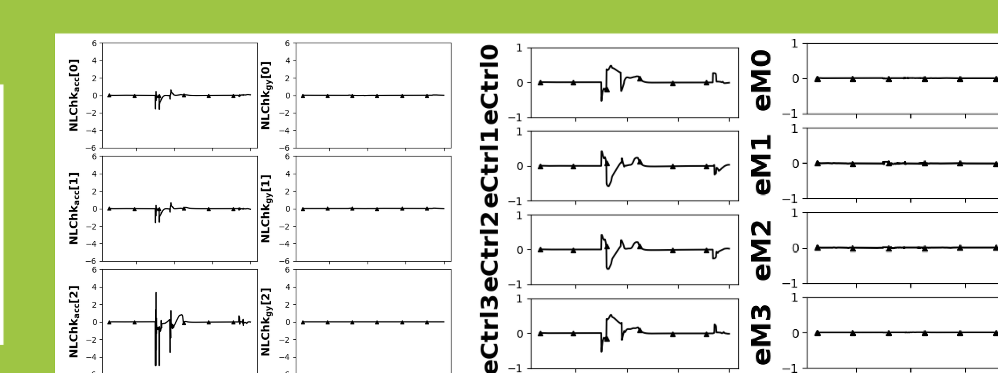


Hierarchical check for quadcopter system

TEST CASE (QUADCOPTER) AND EXPERIMENTAL RESULTS

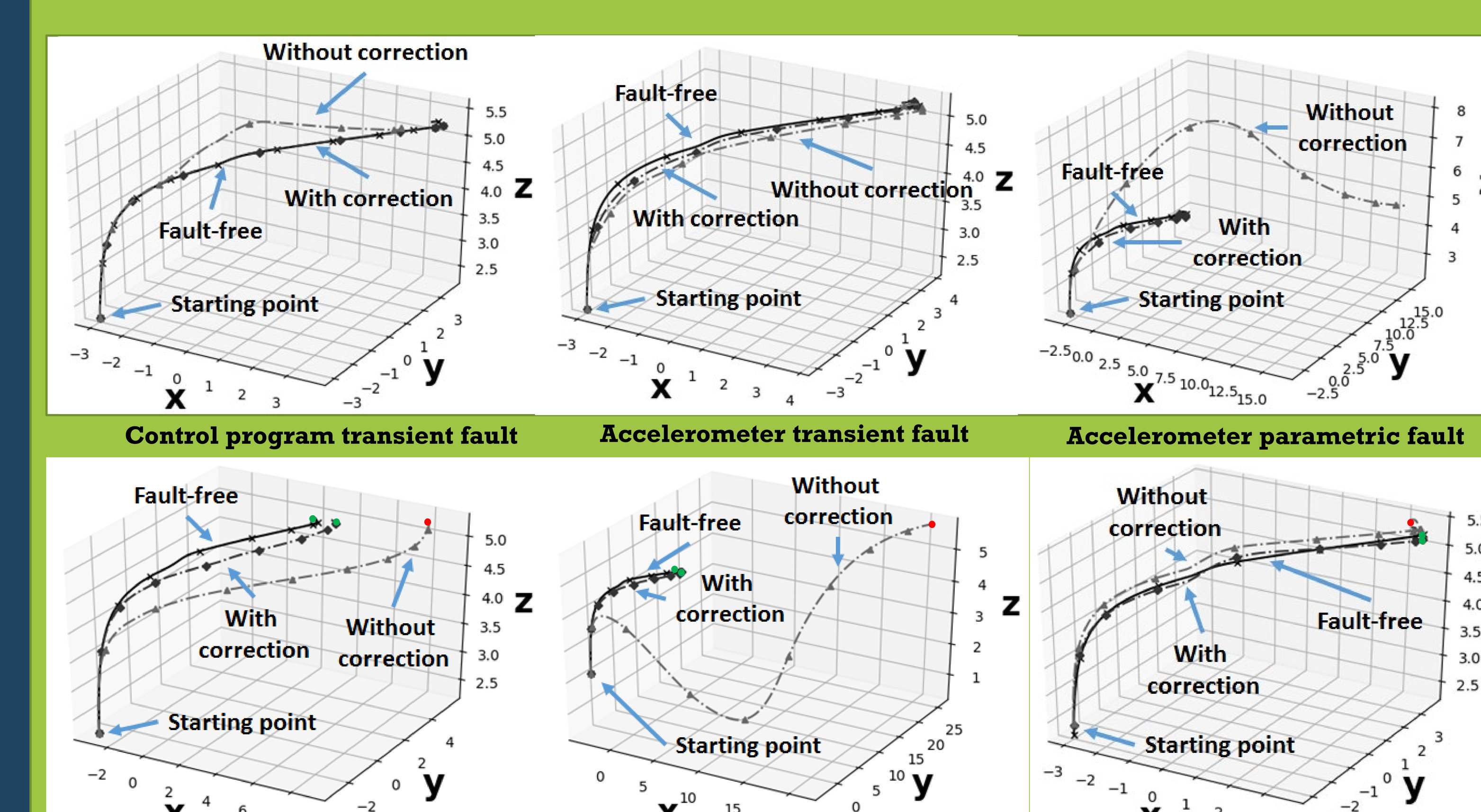


- 12 state variables
- $state = [x, y, z, \dot{x}, \dot{y}, \dot{z}, \phi, \theta, \psi, \dot{\phi}, \dot{\theta}, \dot{\psi}]^T$
- Sensor: Accelerometer and Gyroscope
- Actuator: Brushless DC motor



System check | Control check | Motor check

Transient fault is injected in control program. Detected and diagnosed in system check and control check



Control program transient fault | Accelerometer transient fault | Accelerometer parametric fault

Gyroscope transient fault | Gyroscope parametric fault | Actuator parametric fault