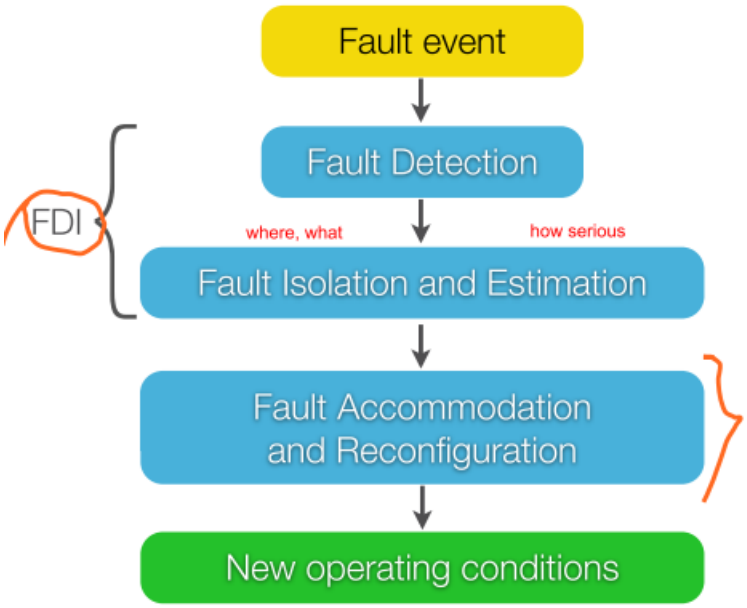
01_Introduction

1. Introduction

Control Process with Fault Tolerance



Redundancy

- **Hardware Redundancy**: switching or major voting logic
- **Physical Redundancy:** over-design
- **Analytical Redundancy:** model, observer ...

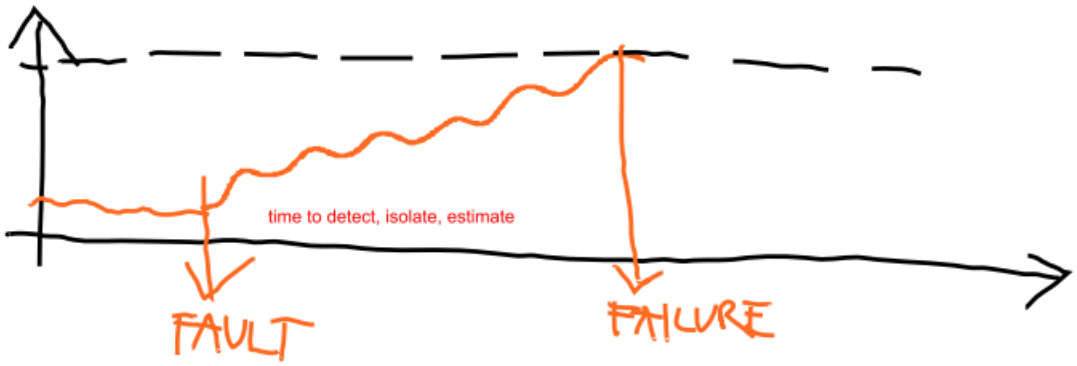
Definitions

Definition: Faults

A **fault** in a dynamical system is a **deviation** of the system **structure** or the system **parameters** from the **nominal** situation

Definition: Failure:

A **failure** is a **permanent interruption** of a system's ability to **perform** a **required function** under specified operating conditions



Definition: Reliability

Ability of a system to **perform a required function** under stated conditions, within a given scope, during a given period of time

$$\mathrm{MTTF} = \frac{1}{\lambda}$$

- MTTF: mean time to failure
- λ: average number of failure per unit time

Definition: Availability

Probability that a system or equipment will operate satisfactorily and effectively at any period of time

$$\mathrm{A} = \frac{\mathrm{MTTF}}{\mathrm{MTTF} + \mathrm{MTTR}}$$

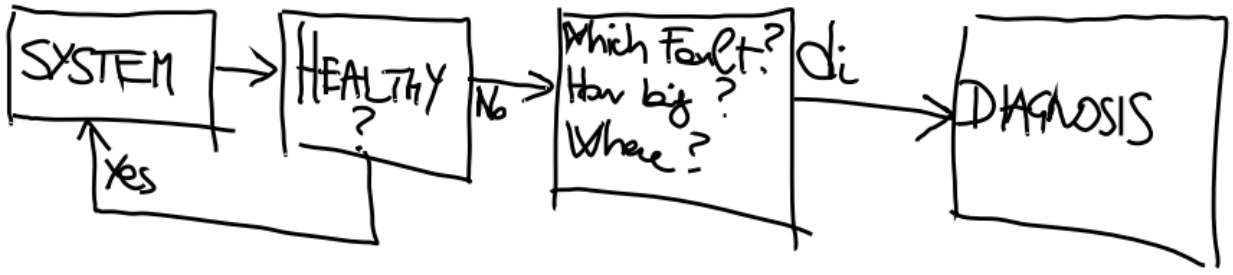
- MTTR: mean time to repair

Definition: Fault Detection

Fault detection consists in **determining the presence** of a fault in a given system at a given time

Definition: Fault Diagnosis

Fault diagnosis consists in determining the **presence, type, size and location** of a fault in a given system at a **given time**, assuming the knowledge of the possible faults affecting that given system



Definition: Fault Tolerance

Fault tolerance is defined as the **possibility** of **achieving** a given (set of) **objective**(s) in the presence of a given (set of) faults

Models

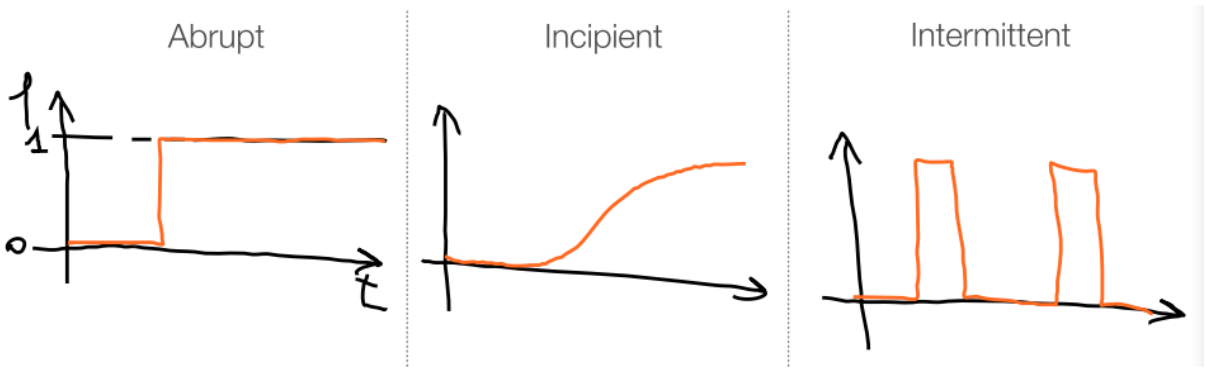
Dynamical System Models

$$\begin{aligned} \dot{x} &= g(x, u, w, \rho) \\ y &= h(x, u, v) \end{aligned}$$

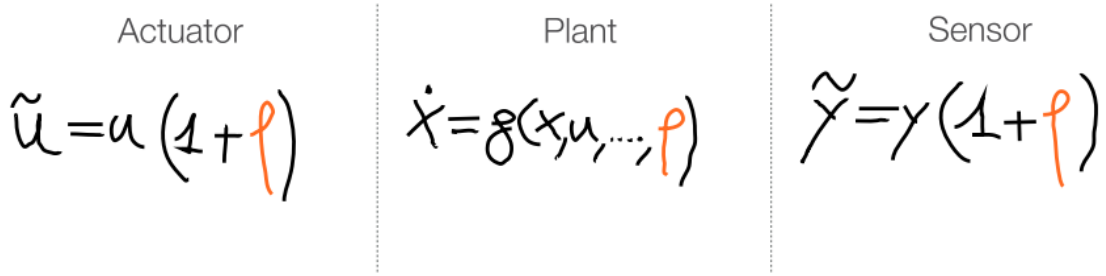
- w, v are uncertainty
- ρ is the fault appearance: $\rho \in [0, 1]$

Faults Model

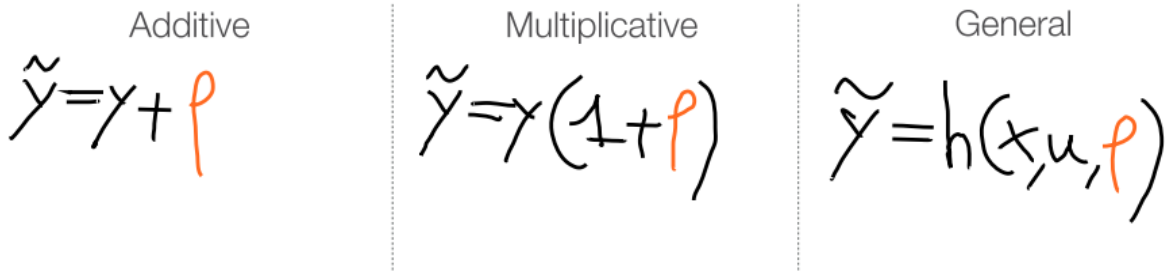
- Magnitude



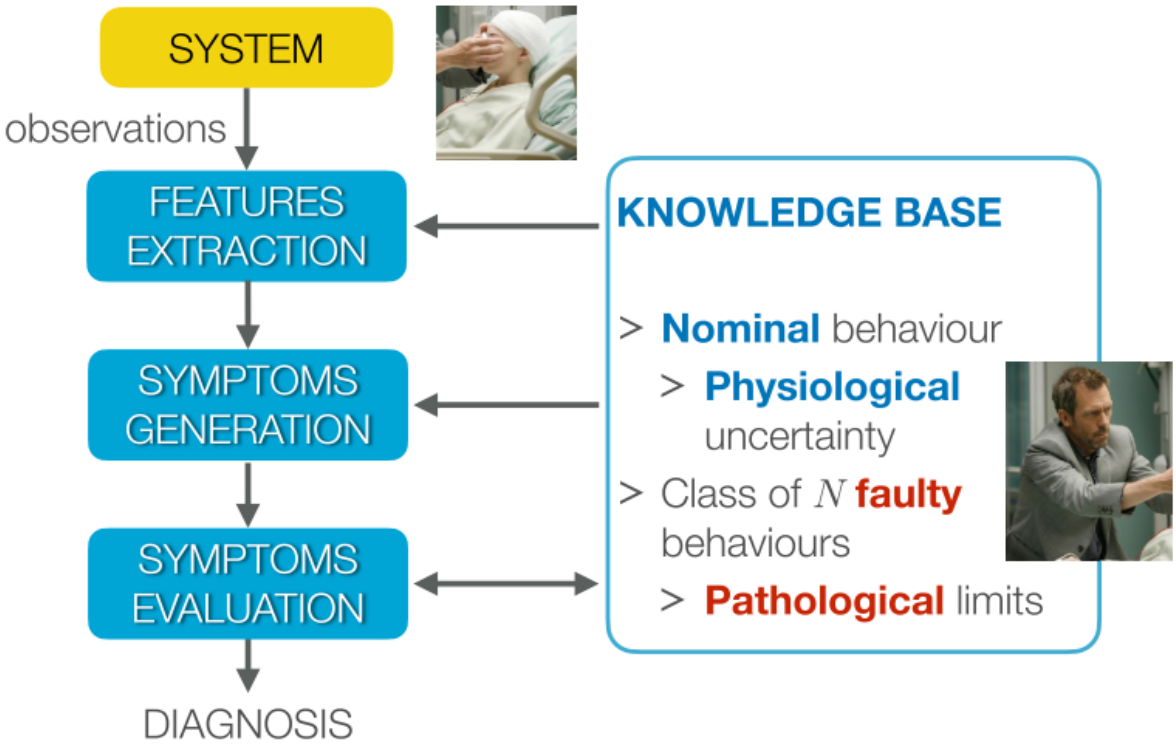
- Location



- Analytical Model



2. Fault Diagnosis Approaches



Feature Extraction

Signal-Based Method

- Raw value
- Mean, Std in a time window
- Peak values
- Fourier analysis
- Cepstrum

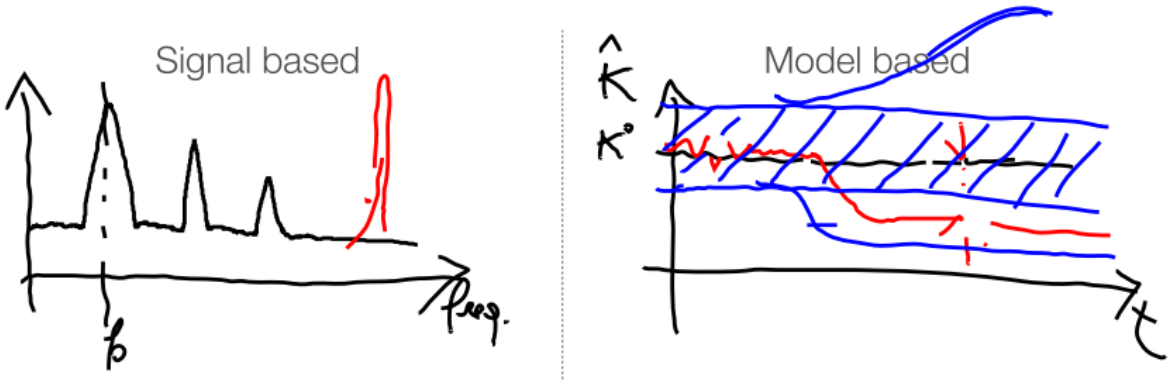
Model-Based Method

- Estimation error of observer (compared to expected value)
- Parity space relation: $\dot{x} = v$
- Estimate Parameter: for example, for a spring, estimate K based on $x, \dot{x}, \ddot{x}$, if $K \neq K_0$, fault

Symptoms Generation

Definition: Symptom

In FD, a **symptom** is a measure of the **difference** between **actual** value of **features** extracted from observations, and **nominal** ones



Symptoms Evaluation

- **Physiological** changes shall be **ignored**, **pathological** changes should be **evaluated**
- A measure of a symptom is so compared against a known **pathological threshold**
- In general, this is a **change detection problem**

Diagnosis

1. Detection

   Testing the null hypothesis:

   $$\mathcal{H}_0 : \text{"Is the system behaving in a nominal way?"}$$

2. Isolation

   Testing N faulty hypotheses:

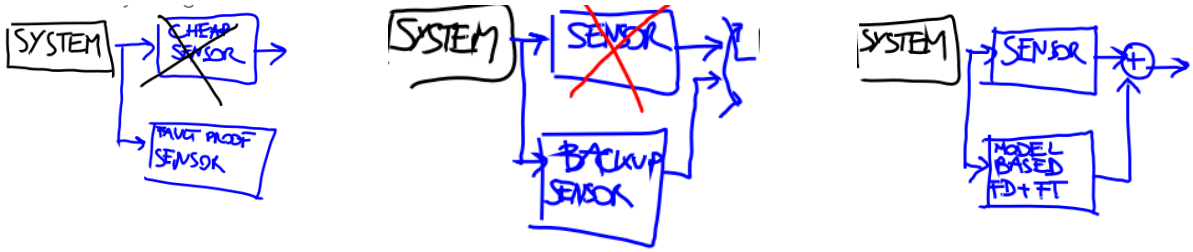
   $$\mathcal{H}_i : \text{"Is the system behaving as if the } i\text{-th fault is present?"}$$

3. Identification/Estimation
   - If $\mathcal{H}_0$ and every but one $\mathcal{H}_i$ are falsfied: estimate parameters of i-th fault
   - If $\mathcal{H}_0$ and every $\mathcal{H}_i$ are falsfied, identify model a new fault

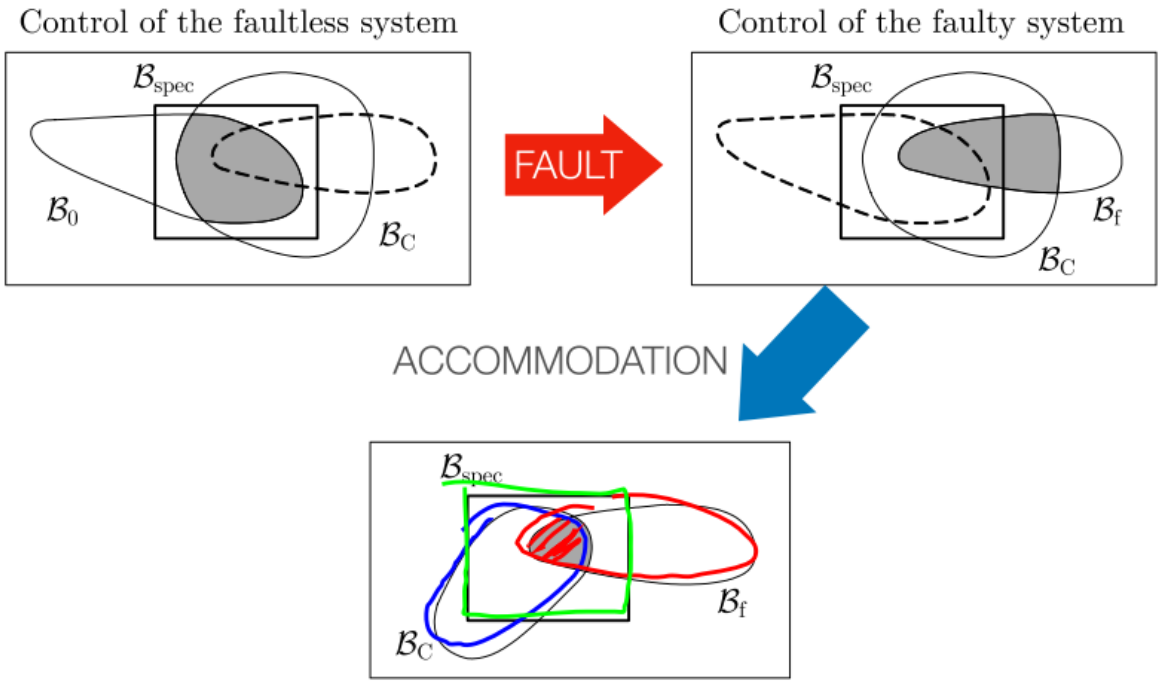
Fault Tolerance Approaches

Approaches

- By design
- By switching
- By adaptive



Behavior Diagram View



Change the controller to set the behavior under fault to a normal range.

Summary

- Process of Fault Tolerance Control: FDI+ FAR → new operating conditions
- Redundancy: hardware, physical, analytical
- Definitions: fault, failure, reliability, availability
- Models: fault model (transient, incipient, intermittent)
- Fault Diagnosis Approach
  - Feature Extraction: signal-based, model-based
  - Symptoms Generation

    - Symptoms Evaluation: pathological evaluated
    - Diagnosis: Test Hypotheses
- Fault Tolerance Approaches
    - Approaches: design, switch, adaptive
    - Behavior Graph