AUTONOMOUS FAULT DIAGNOSIS : STATE OF THE ART AND AERONAUTICAL BENCHMARK

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3rd European Conference for Aero-Space Sciences

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THE FRENCH AEROSPACE LAB

retour sur innovation

Outline

Introduction
- Context
- Fault diagnosis : definitions
- Fault diagnosis : principles

Fault Detection and Isolation
- Model-free methods
- Model-based methods
- Residual analysis and robustness

Aeronautical benchmark
- Aircraft model
- Fault scenario
- Methods to be investigated

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Context

In-flight securement of aircrafts without adding sensors

1. « Securing » : early detection of abnormal operating modes
   $\Longrightarrow$ *Fault Detection and Isolation (FDI)*
2. « Without adding sensors » : use existing and non-redondant sensors and actuators $\Longrightarrow$ *Analytical Redundancy*
3. « Aircraft » : application to an aeronautical generic case study
   $\Longrightarrow$ *Autonomous FDI*

Methodology

- State of the art in FDI
- Benchmark definition
- Selection of methods

Fault diagnosis : definitions

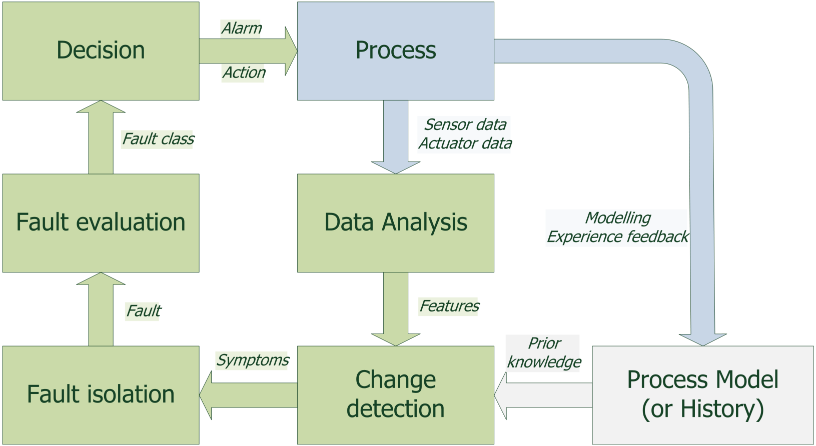
Fault : Unexpected deviation of at least one characteristic property of the system (sensors, actuators, parameters)

Diagnosis : Tasks showing the existence of faults : *Detection, Isolation or Identification*, *Reconfiguration*

Residuals : Signals emphasizing the presence of faults

Model : Here, a knowledge-based dynamical model

Fault diagnosis : principles



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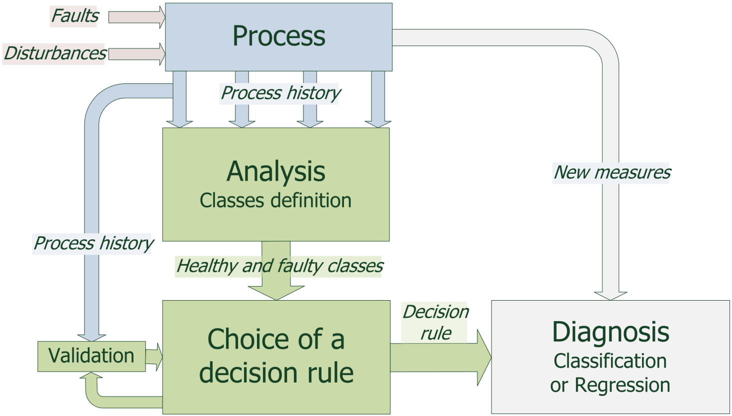
Model-free methods



Decision rules

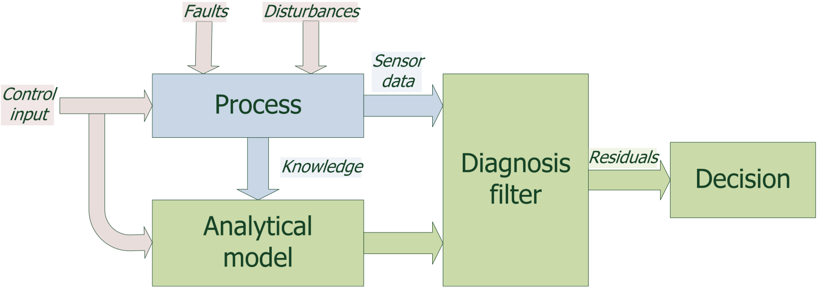
Early tendencies

- *Parametric :* hyperplane, nonlinear function, neural networks
- *Non-parametric :* k-nearest neighbor, histogram methods

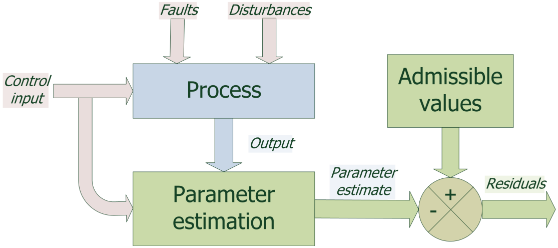
Advanced pattern recognition

- *2 key concepts :* sparsity, kernel trick
- *Methods :* Support Vector Machines (SVM), Gaussian processes

Model-based methods



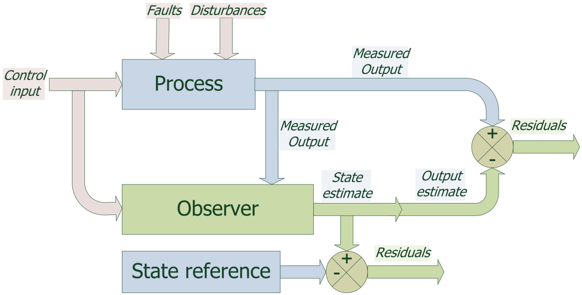
Parameter estimation



Methods

- Least-squares and affiliated techniques
- General optimization procedures

State estimation



Methods

- *Linear systems* : Luenberger observers, Kalman filtering, unknown-input observers
- *Nonlinear systems* : nonlinear observers, particle filtering

Decoupling approach

The *Fundamental Problem of Residual Generation (FPRG)*

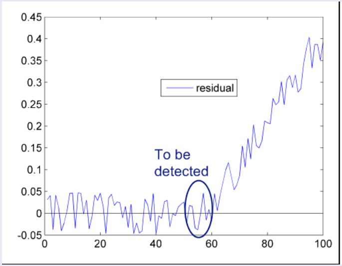
- Sensitivity to disturbances should be minimum
- Sensitivity to faults should be maximum
- Each residual should ideally be sensitive to one fault

Methods

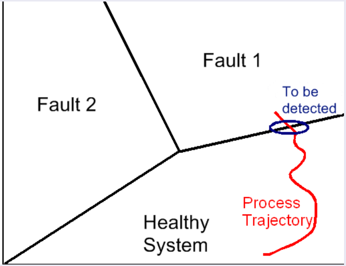
- Parity space (linear, bilinear and polynomial systems)
- Nonlinear geometric approach
- Multi-objective optimization (H_∞ methodology)

Residual analysis

Residual analysis



Model-based



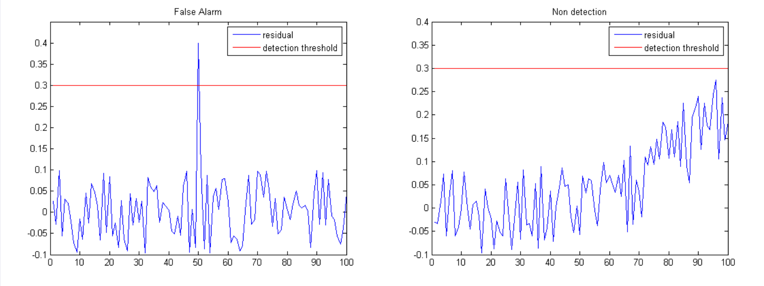
Model-free

Tools for residual analysis

- Fixed or adaptive thresholding
- Statistical tests (Wald, Page-Hinkley ...)

Robustness issues in FDI

Trade-off between false alarm and non-detection



Algorithms should be robust to :

- Disturbances
- Measurement noise
- Modelling uncertainty

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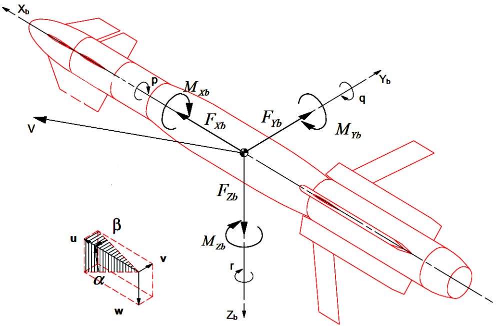
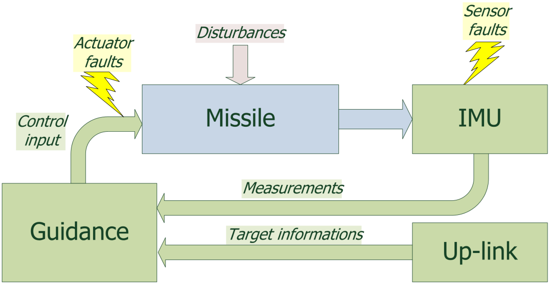
Case study : 6-DOF surface-to-air missile



Features

- *State variables* : position, speed, angular velocity, Euler angles
- *Actuators* : flight control surfaces (roll, pitch, yaw) and propulsion
- *Sensor* : Inertial Measurement Unit (IMU)

Flight scenario



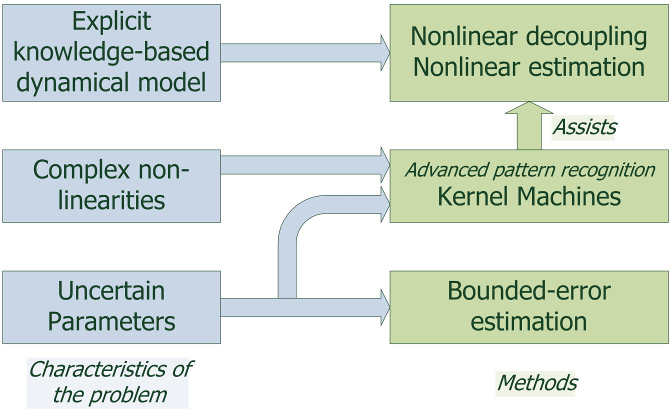
Uncertainty and faults

- *IMU uncertainty* : bias, scale factor, zero-mean Gauss. white noise
- *Sensor faults :* uncertainty parameters out of expected range
- *Actuator faults* : locked-in-place rudder, loss of thrust

Target and missile trajectories

How can we detect these faults ?

Methods to be investigated



Summary and future work

Summary

- Review of FDI methods
- Aeronautical benchmark definition
- Selection of methods

Future work

- Evaluation of selected methods
- Cooperation between approaches
- Diagnosability analysis
- Closed-loop control influence