Fault Diagnosis & Tolerance

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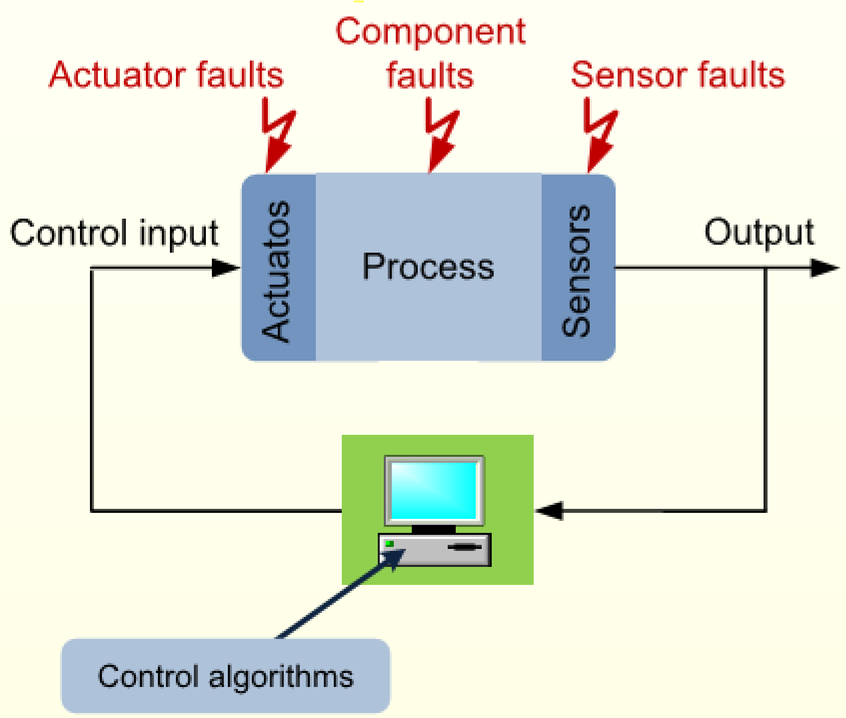
- **Fault** is an un-permitted deviation of at least one characteristic property or parameter of a system from the standard condition



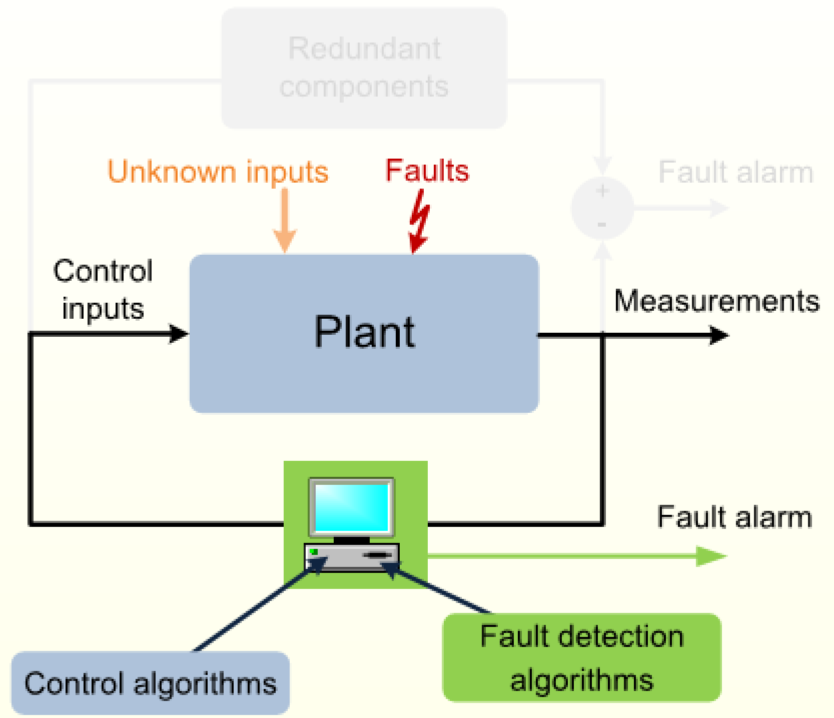
- Faults can affect
  - Efficiency of the process
  - Quality of the product
  - Availability of the plant
  - Safety of the process and environment

- Economic loss

- Fatalities
  - Boeing 747-200F incident, could have been avoided [1]
  - American Airline DC10 incident, could have been avoided
  - BP's Texas City Accident

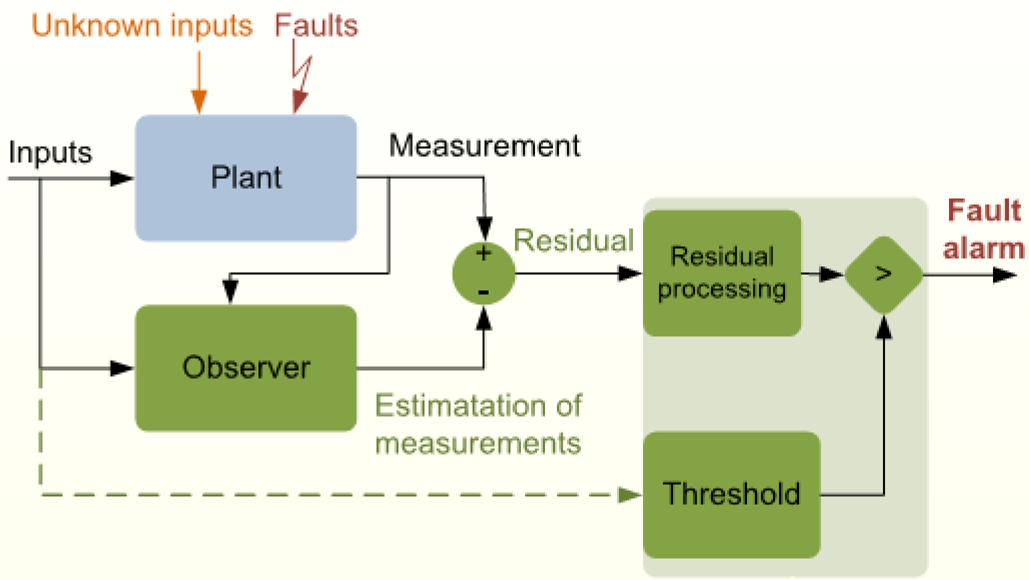
Early detection of faults can help to avoid economic losses and fatalities

Hardware Redundancy vs. Analytical redundancy



- **NO** (less) additional hardware for analytical redundancy
- Less weight and less space
- Less cost

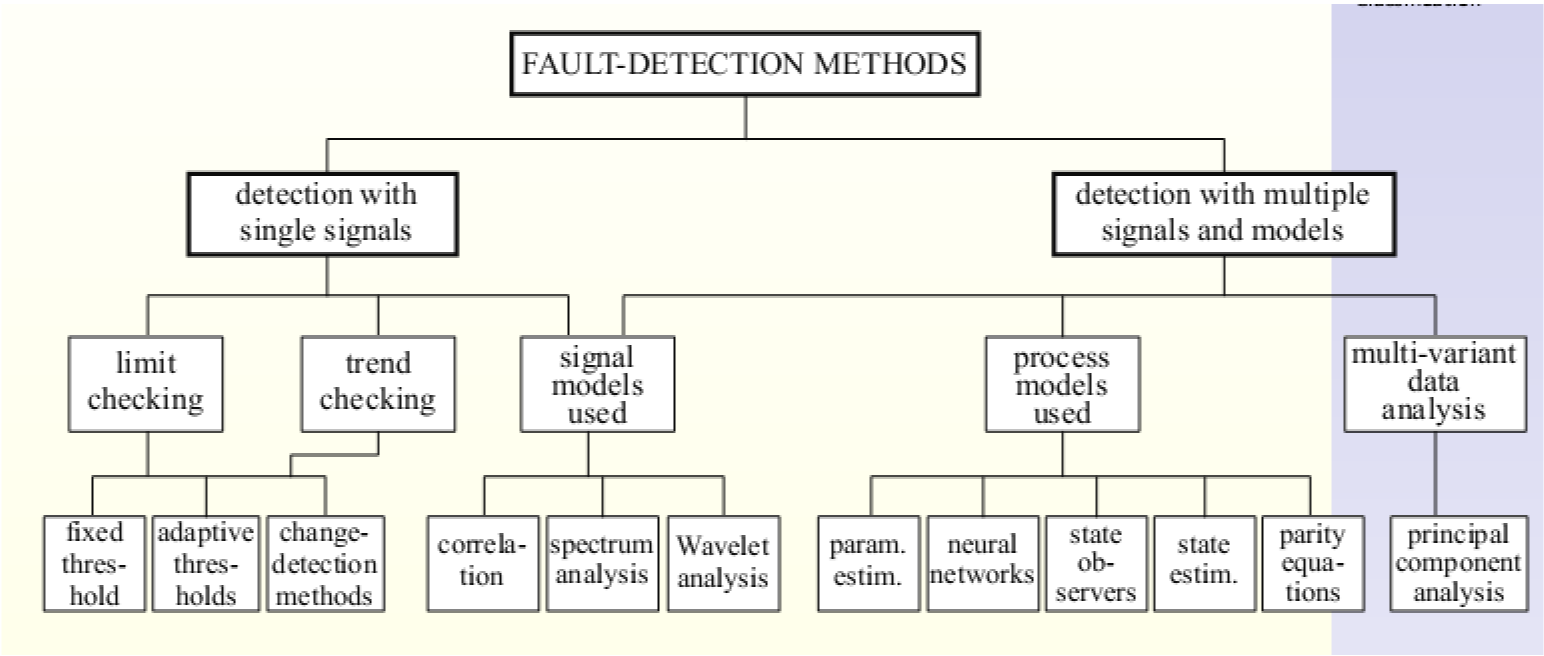
Overview



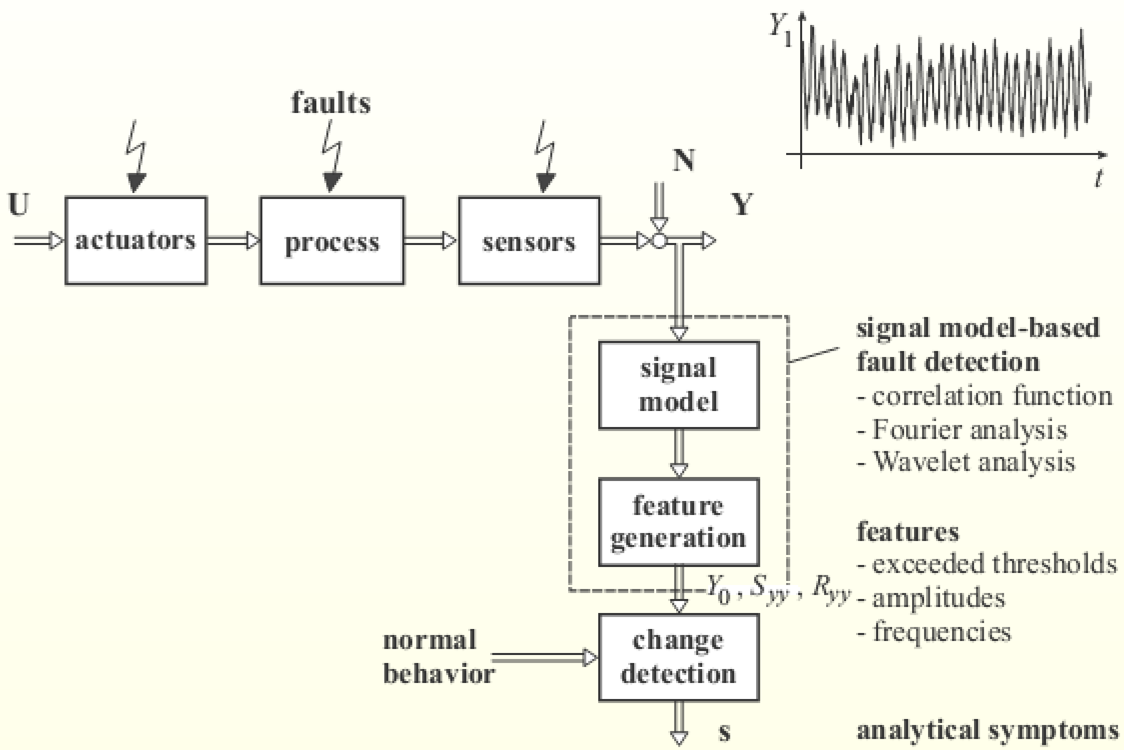
1. Generation of **residual signal** which is sensitive to faults and robust against unknown inputs

2. Computation of a **threshold** to care for the effect of unknown inputs

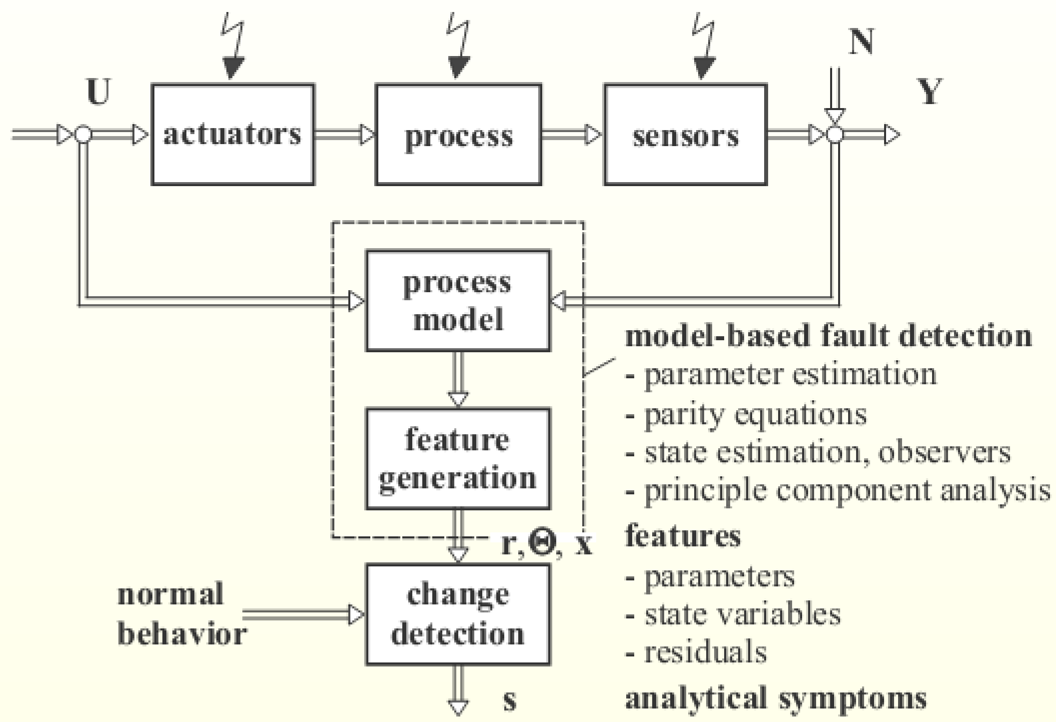
Classification



Signal-Model Based Fault Detection



Process-Model Based Fault Detection



Desirable Features of Fault Detection Schemes

- Early detection of faults
- Robustness against disturbances and uncertainties
- Online implementation
- Simple design procedure

Comparison of Fault Detection Schemes

- Hardware redundancy vs. Analytic redundancy
- Process model based vs. signal based
- Observer-based, parameter estimation, parity space

Comparison of Fault Detection Schemes

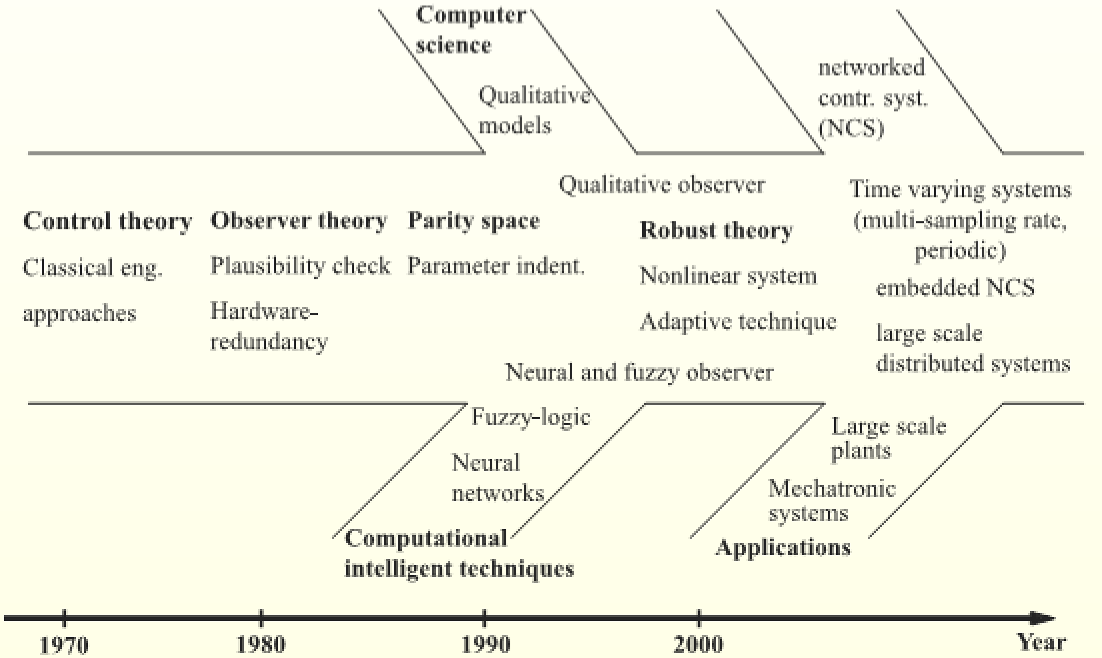
criteria	**parity equations**	**state estimation**		**parameter estimation**
		state observer	output observer	
assumptions				
model structure	exactly known	exactly known		known
model parameters	known, constant	known, constant		unknown, time-varying
disturbance models for unknown inputs	exactly known	exactly known		exactly known
noise	small	small		medium
stability of detection scheme	no problem	depends on design	no problem	no problem
excitation by the input	additive faults: no multiplicative faults: yes	additive faults: no multiplicative faults: yes		additive faults: no multiplicative faults: yes

Comparison of Fault Detection Schemes

detectable faults			
abrupt	yes	yes	yes
drift	yes	yes	yes
incipient	yes	yes	yes
single faults	yes	yes	yes
multiple faults	SISO: no MIMO: yes	SISO: no MIMO: yes	SISO: yes MIMO: yes
fault isolation	MIMO: yes	MIMO: yes	SISO: yes MIMO: yes
additive	yes	yes	yes
multiplicative	no	no	yes
general			
robustness parameter changes	problematic	problematic	unproblematic
nonlinear processes	many classes possible	limited	many classes possible
static processes	yes	no	straightforward
computational effort	small / medium	medium	medium / larger
closed loop	yes	yes	yes, exter- nal excitation

Historical Background

- As old as human beings developed machines
- Hardware redundancy
- Developed as a field in 1970's with the advent of microcomputers



Further Readings

- R. J. Patton, "Fault-tolerant control: the 1997 situation," in *Proc. IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes*, (Kingston Upon Hull, UK), pp. 1029–1051, IFAC, 1997
- C. Edwards, T. Lombaerts, and H. Smaili, *Fault Tolerant Flight Control: A Benchmark Challenge*, vol. 399. Springer, 2010, **Chapter 1**
- R. Isermann, *Fault-diagnosis systems: an introduction form fault detection to fault tolerance*. Springer, 2006, **Chapter 1, Chapter 14**
- S. X. Ding, *Model-based fault diagnosis techniques - design schemes, algorithms and tools*. Springer, 2008, **Chapter 1**