Modelling a fleet of machine (using principal component analysis)

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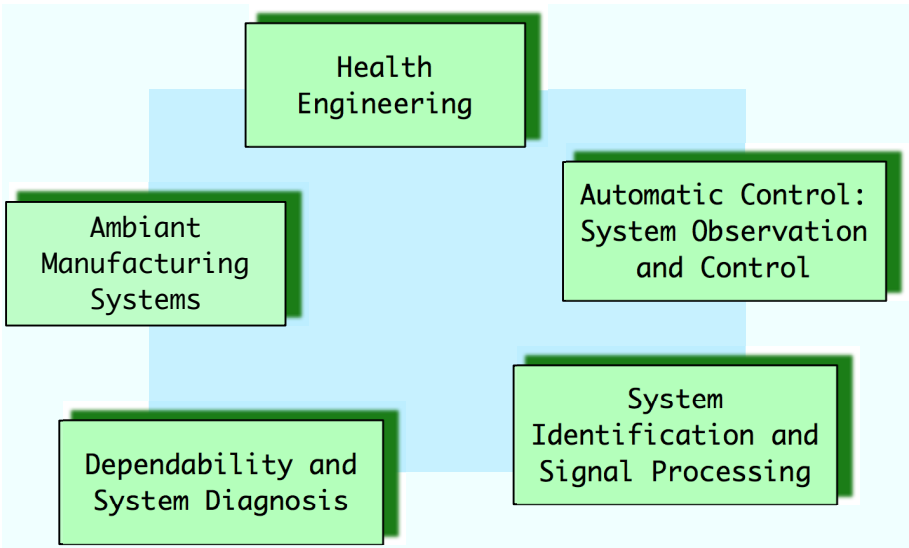
1. Generalities

The « Centre de Recherche en Automatique de Nancy » (Automatic Control) is a Research Centre funded by the "Centre National de la Recherche Scientifique (CNRS)" and two universities in Nancy : UHP (Université Henri Poincaré) and INPL (Institut National Polytechnique de Lorraine).

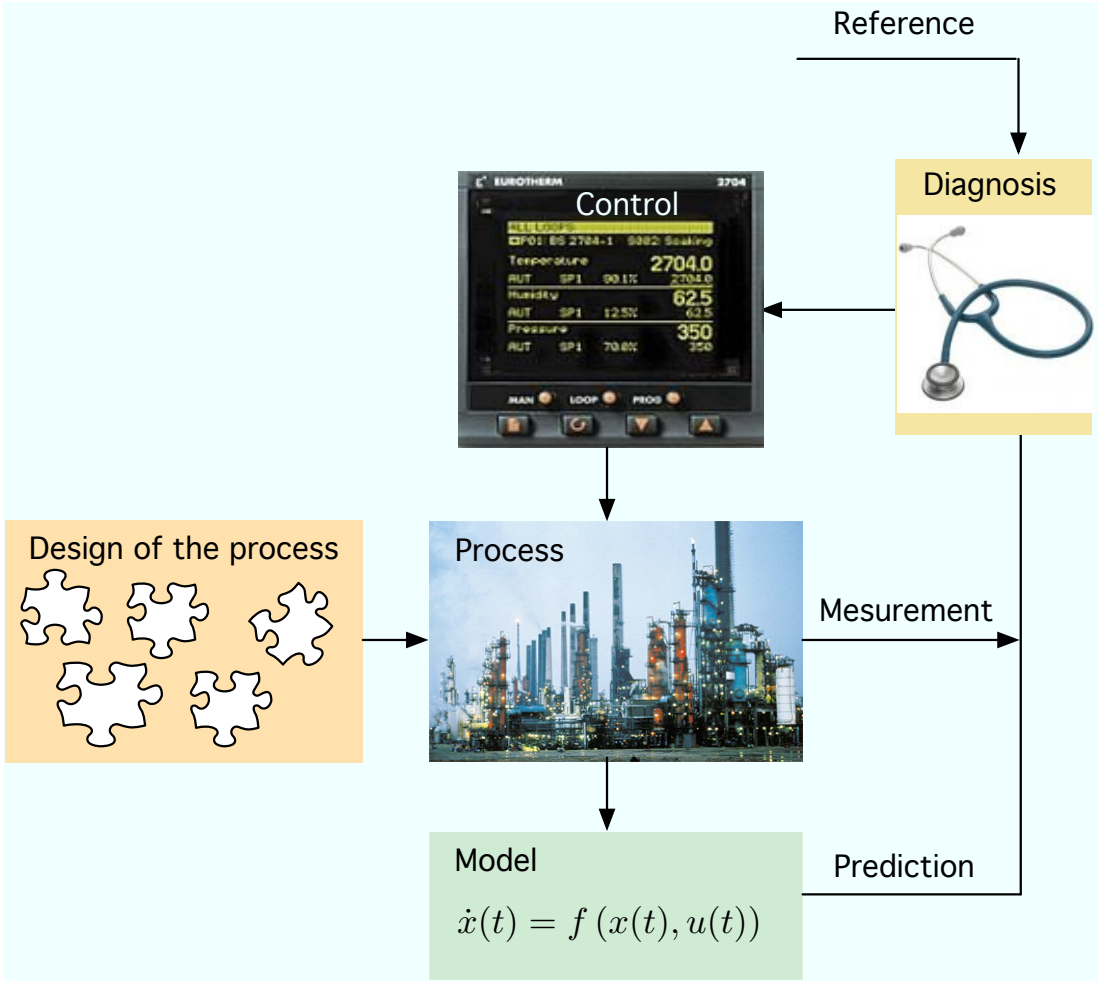
The CRAN was set up in Nancy (France) in 1980. It totals 200 persons. The research activities concentrate on 5 principal themes :

- Systems Observation and Control
- System Identification and Signal Processing
- Dependability and System Diagnosis
- Health Engineering
- Ambient Manufacturing Systems.



- Process diagnosis
- Diagnosis based on data analysis
- Work of Farak Ankoud (Thesis defense on 12 december 2011)
- Research agreement CIFRE with Direction des Etudes et Recherches d'EdF

1.3 Process supervision



1.4 Steps of system monitoring

For the elaboration of a global approach for the design and the operation (supervision, maintenance, reconfiguration) of complex automated industrial systems, it is necessary :

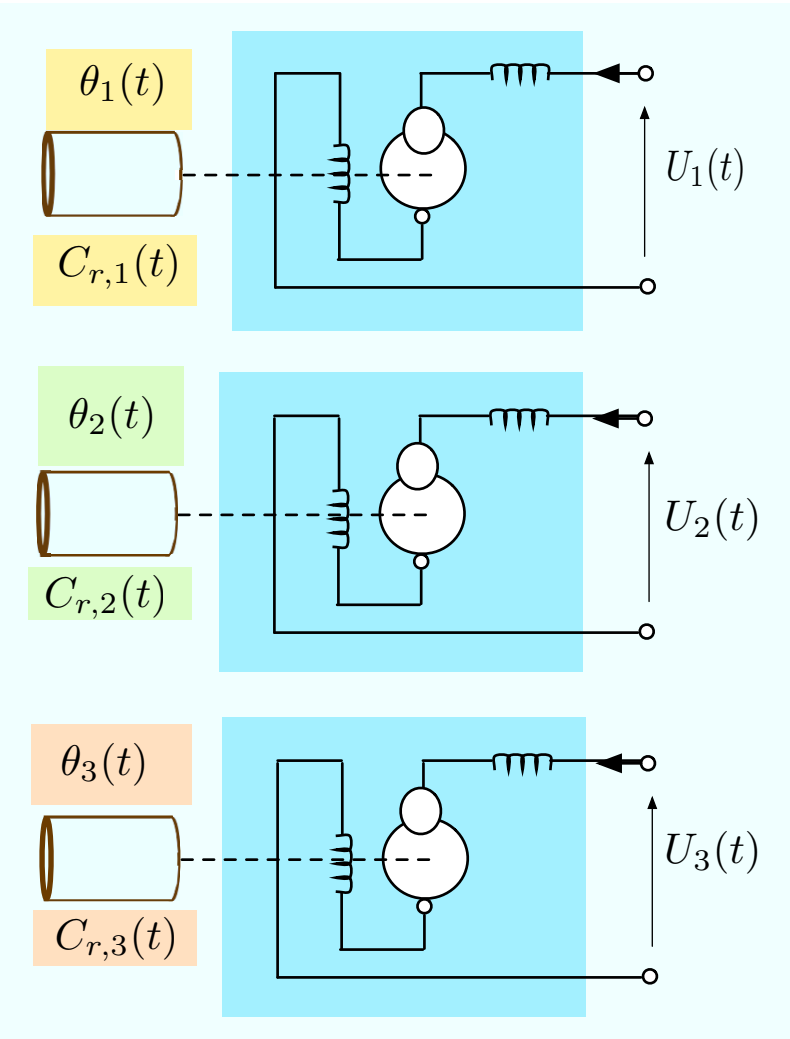
- to guarantee the system safety
- to forecast alternate modes
- to detect « any » fault
- to isolate the faults
- to identify the faults
- to forecast the evolution of the faults
- to quantify the criticality of the faults
- to be sure of the diagnosis
- to give the diagnosis as soon as possible

- to compensate the fault influence

2. Fleet effect

Definition and objectives

- Fleet of machines : a collection of machines a priori identical
- Estimating a generic model for a fleet of identical machines
- Deduce a generic strategy for the diagnosis of a fleet of machines



Motivations

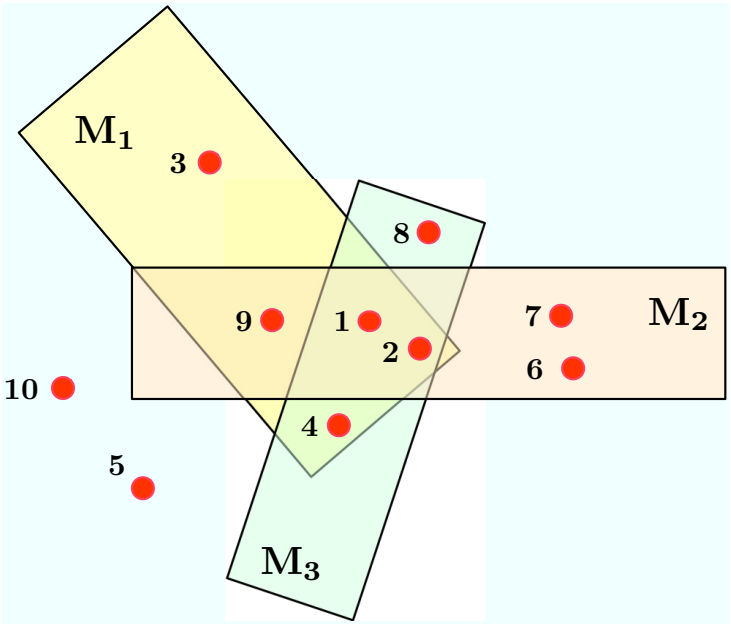
- Reducing the cost of estimating the model of each machine
- Facility to construct the model of a new machine
- Facility to replace a machine by another one
- Reducing the cost of system maintenance

Historical point of view

- Multitask learning
  `http://books.nips.cc/papers/files/nips19/NIPS2006-0251.pdf`
- Fleet Maintenance Systems
  `http://www.serco-na.com/Download.aspx?ID=288&Type=Story`
- Fleet Inventory Tracking
  `http://www.mex.com.au/Products/FleetMEX.aspx`
- Patents on fleet of machines
  `http://www.freepatentsonline.com/5737215.html`

- The problem consists in determining if a generic model representing the normal behavior of each machine of the fleet can be established.
- A generic model is composed of two parts :
  - a common part made up of the variables of the machine itself
  - a distinct part related to the environmental variables.
- The work deals with :
  - classification : extraction of the variables shared by the models
  - identification of the model parameters with equality constraints

Exemple : 3 machines M_1, M_2 et M_3 with 10 variables



	1	2	3	4	5	6	7	8	9	10
M_1	×	×	×	×	×	.	.	.	×	×
M_2	.	×	×	.	×	.	×	.	×	.
M_3	.	×	×	×	×	.	.	×	.	.

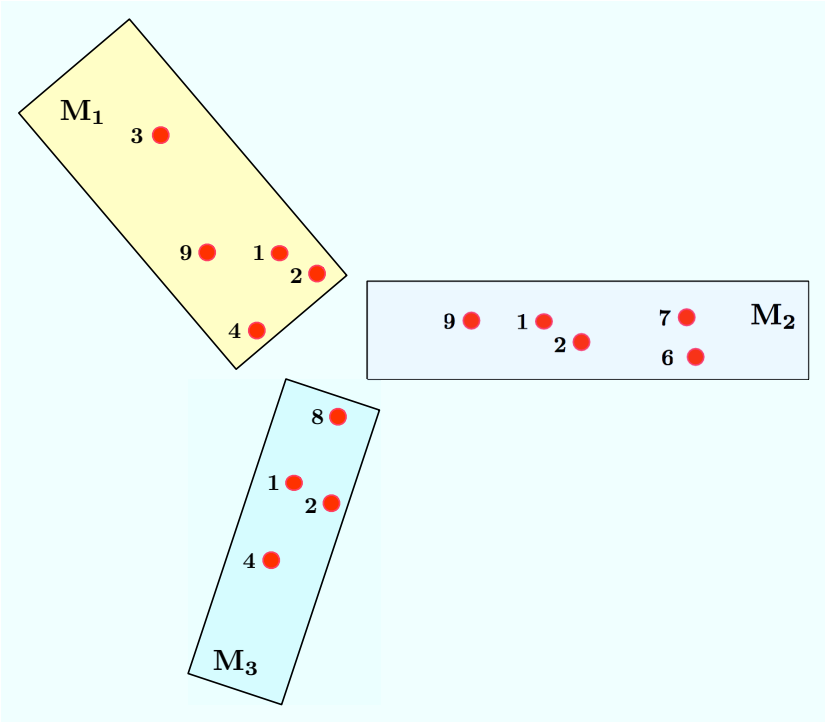
Strong fleet effect : *Variables* 2, 3, 5

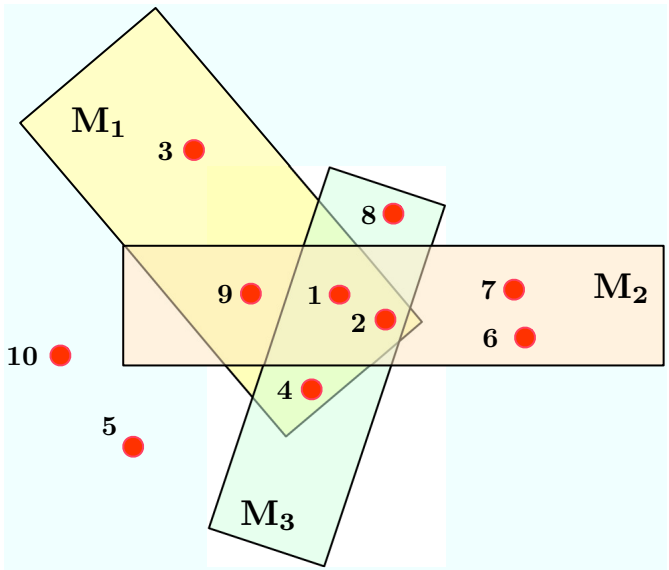
Low fleet effect : *Variables* 4, 9

Local effect : *Variables* 1, 7, 8, 10

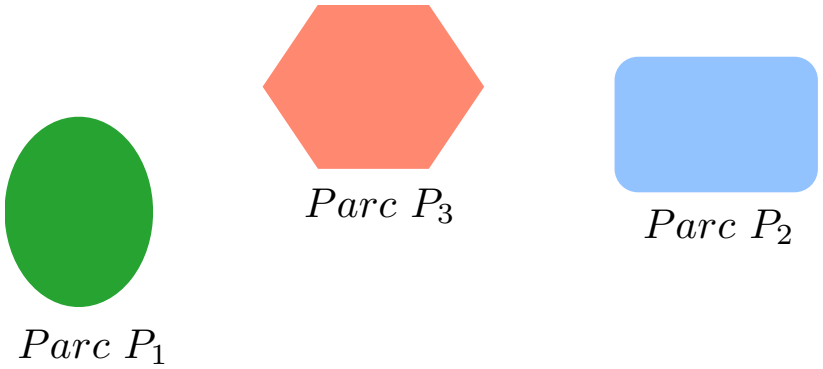
2.3 Modelisation of a fleet of machines : principle

1. Modelisation of each machine considered independently of the other
2. Search the variables common to the different machines
3. Search the parameters common between the machines variables
4. Modelisation of the fleet of machine under equality constraints
5. Model validation





2.4 Modelisation of each machine considered independently of the other



Strategy

- Search the number of models describing each machine
- Identify the structure of each model
- Identify the parameters of each structure

	1	2	3	4	5	6	7	8	9	10
M_{11}	×	×	×	×	×	.	.	.	×	×
M_{12}	.	×	.	.	.	×	.	.	.	×
M_{21}	.	×	×	.	×	.	×	.	×	.
M_{22}	.	×	.	.	.	×	.	×	.	×
M_{23}	.	.	×	.	.	.	.	.	.	.
M_{31}	.	×	×	×	×	.	.	×	.	.
M_{32}	×	×	.	.	×	×	.	.	.	×

- Validation of each model using a new database

How to hIghlight the fleet effect ?

	1	2	3	4	5	6	7	8	9	10
M_{11}	×	×	×	×	×	.	.	.	×	×
M_{12}	.	×	.	.	.	×	.	.	.	×
M_{21}	.	×	×	.	×	.	×	.	×	.
M_{22}	.	×	.	.	.	×	.	×	.	×
M_{23}	.	.	×	.	.	.	.	.	.	.
M_{31}	.	×	×	×	×	.	.	×	.	.
M_{32}	×	×	.	.	×	×	.	.	.	×

- ▷ Search the variables with strong explanatory power
- ▷ Among these variable, search those common to several machine models
- ▷ Among them search the variables with close coefficients
- ▷ New parameters identification with equality constraints

3. Numerical aspects

Model from the first database, 250 observations and 7 variables

Eigenvalues :

-0.01	0.02	24.08	30.9	33.4	52.4	172.7

Eigenvectors :

0.70	0.07	0.18	0.14	-0.10	0.53	0.39
-0.21	0.46	-0.03	-0.10	0.11	-0.29	0.78
0.56	-0.42	-0.17	-0.18	0.16	-0.62	0.11
-0.37	-0.77	0.09	0.05	-0.02	0.21	0.44
-0.00	-0.00	-0.35	0.61	0.69	0.09	0.01
-0.00	0.00	0.26	0.73	-0.46	-0.41	0.02
0.00	0.00	-0.85	0.05	-0.49	0.11	0.09

Normalised eingenvectors

1.00	0.00	0.18	0.14	-0.10	0.53	0.39
0.00	1.00	-0.03	-0.10	0.11	-0.29	0.78
0.50	-1.00	-0.17	-0.18	0.16	-0.62	0.11
-1.00	-1.50	0.09	0.05	-0.02	0.21	0.44
-0.00	-0.00	-0.35	0.61	0.69	0.09	0.00
-0.00	0.00	0.26	0.73	-0.46	-0.41	0.02
0.00	0.00	-0.85	0.05	-0.49	0.11	0.09

3.1 Example with three databases

Models obtained from the three databases

$BD1$	
1.00	0.00
0.00	1.00
0.50	-1.00
-1.00	-1.49
-0.00	-0.00
-0.00	0.00
0.00	0.00

$BD2$		
1.00	0.00	-0.00
-0.00	**1.00**	-0.00
-0.00	0.00	**1.00**
0.50	-0.50	1.00
0.50	**-1.48**	**-2.01**
0.00	-1.00	0.00
0.00	-0.00	-1.00

$BD3$		
1.00	-0.00	0.00
0.00	**1.00**	0.00
0.00	0.00	**1.00**
-1.50	-0.00	1.52
-0.00	**-1.51**	**-1.98**
1.00	2.00	1.00
-1.00	-1.00	0.00

variables Mod M_1	variables Mod M_2	variables Mod M_3
M_{11} : 1,3,4	M_{21} : 1,4,5	M_{31} : 1,4,6,7
M_{12} : 2,3,4	M_{22} : 2,4,5,6	M_{32} : 2,5,6,7
	M_{23} : 3,4,5,7	M_{33} : 3,4,5,6

▷ Distances between M_{11} and $\{M_{21}, M_{22}, M_{23}, M_{31}, M_{32}, M_{33}\}$, M_{12} and $\{M_{21}, \ldots\}$ ...

▷ Proximity analysis between the distances ⇒ variables and common parameters.

4. Formalisation

Local treatment of each database

Database 1 : X_1

Model parameters : θ_1

Criterion : $\Phi_1 = \| X\theta_1 \|^2$

Constraint : $\| \theta_1 \|^2 = 1$

$$\theta_1 = \underset{\theta_1}{\text{argmax}}\ \Phi_1$$

$$(X_1^T X_1 - \lambda_1 I)\theta_1 = 0$$

Database 2 : X_2

Model parameters : θ_2

Criterion : $\Phi_2 = \| X\theta_2 \|^2$

Constraint : $\| \theta_2 \|^2 = 1$

$$\theta_2 = \underset{\theta_2}{\text{argmax}}\ \Phi_2$$

$$(X_2^T X_2 - \lambda_2 I)\theta_2 = 0$$

Database 3 : X_3

Model parameters : θ_3

Criterion : $\Phi_3 = \| X\theta_3 \|^2$

Constraint : $\| \theta_3 \|^2 = 1$

$$\theta_3 = \underset{\theta_3}{\text{argmax}}\ \Phi_3$$

$$(X_3^T X_3 - \lambda_3 I)\theta_3 = 0$$

Proximity analysis of
θ_1 and θ_2, θ_2 and θ_3, θ_3 and θ_1

Global traitement under equality constraints

▷ Estimation criterion :

$$\Phi = \| X_1 S_1 \theta_1 \|^2 + \| X_2 S_2 \theta_2 \|^2 + \| X_3 S_3 \theta_3 \|^2$$

The matrices S_1, S_2 and S_3 select the retained variables.

▷ Constraints of proximity :

$$\| \theta_1 \|^2 = 1 \qquad \| \theta_2 \|^2 = 1 \qquad \| \theta_3 \|^2 = 1$$

$$H_{11}^T \theta_1 - H_{12}^T \theta_2 = 0 \qquad H_{21}^T \theta_1 - H_{22}^T \theta_2 = 0 \qquad H_{31}^T \theta_3 - H_{32}^T \theta_1 = 0$$

where the matrices H_{ij} are used to express the :

- proximity of the coefficients in respect to 0
- proximity of the coefficients between themselves.

▷ Resolution : optimisation with linear constraints

$$\Longrightarrow \quad \hat{\theta}_1, \hat{\theta}_2, \hat{\theta}_3$$

5. Application

LOCAL IDENTIFICATION
without coupling effect

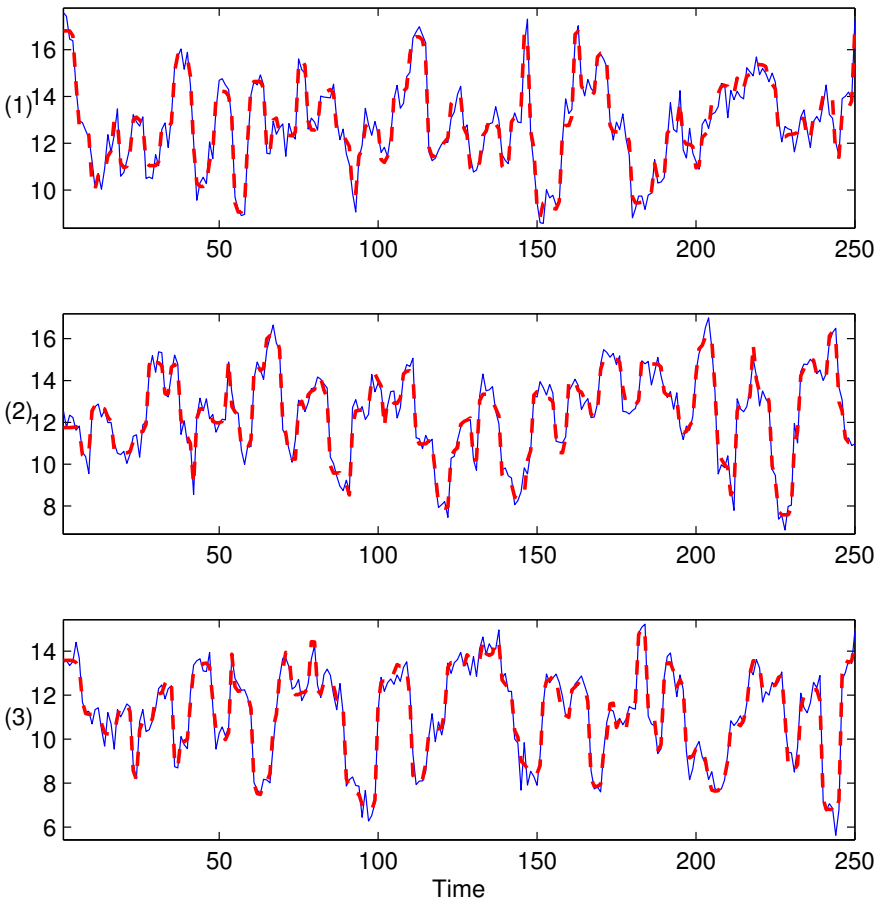


FIGURE: Output y^k (blue solid line) and estimated iutput $\hat{y}^k$ (red dashed line) in each database.

GLOBAL IDENTIFICATION
with coupling effect

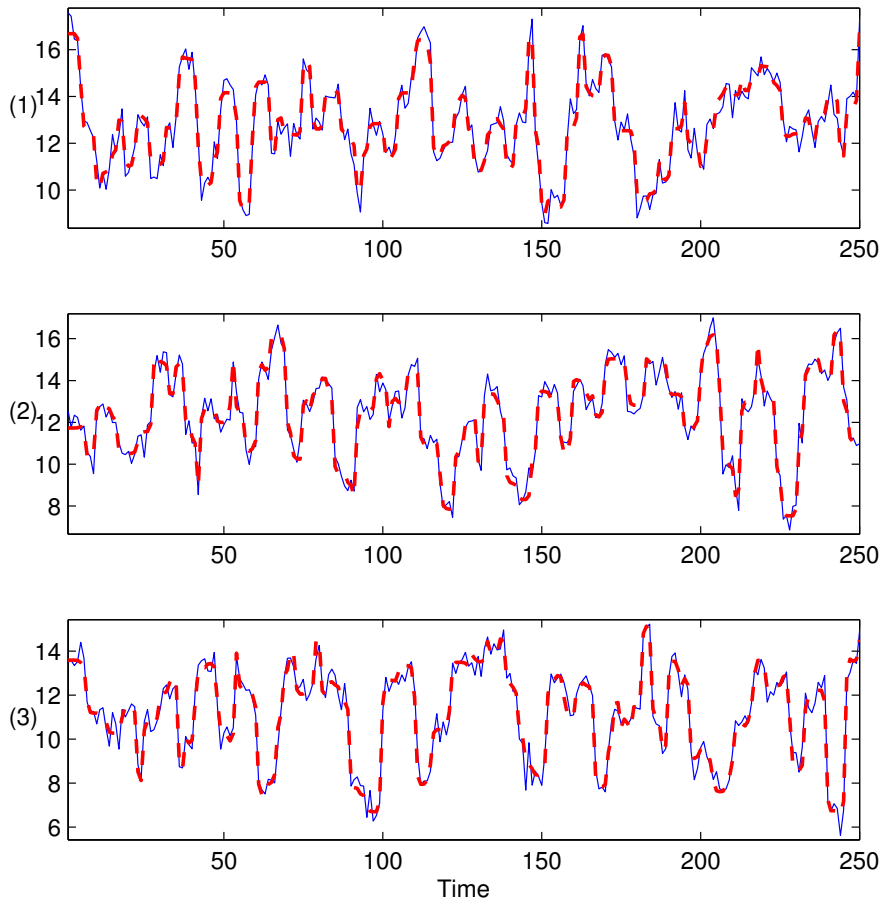
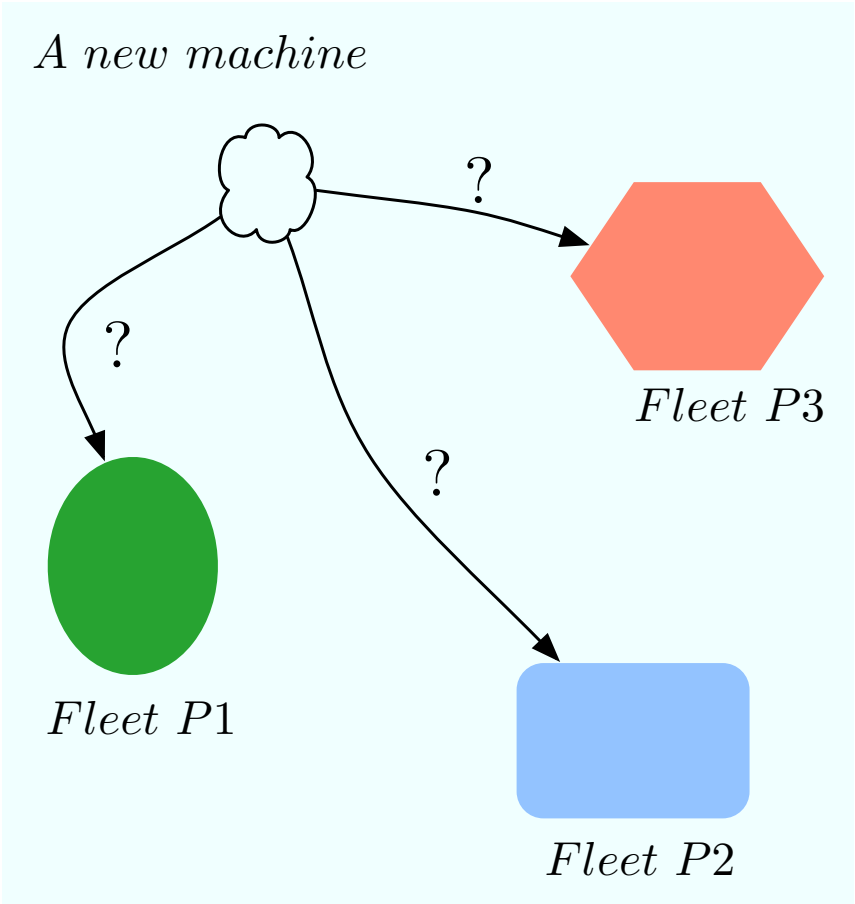


FIGURE: Output y^k (blue solid line) and estimated output $\tilde{y}^k$ (red dashed line) in each database.

Interpretation

5.2 - A new machine is coming !



Conclusion

A new concept to analyse a fleet of components

- A method for identifying the common part of the models in a fleet of presumed identical machines

$$\rightarrow \text{Save time for modeling}$$

- Models describing the normal behavior of the machines are estimated taking into account the common part of the generic model.

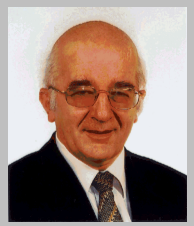
$$\rightarrow \text{Gain complexity for modeling}$$

Perspectives

- The method will be tested on real data collected from different pumps working in several nuclear power plants of EDF.
- Set the minimum number of tests and measurements to determine the allocation of a new machine to an existing fleet.

Thanks for your attention !

Additionnal Informations



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