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Issues on Computer-Aided Process Operation: Modular Networks for Process Modelling and Control

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Plan for the Talk

① **Part I - To say what I am going to say**

② **Part II - To say what I have to say**

③ **Part III - To say what I have said**

To say what I am going to say

① Scope

② Progress in Computer-Aided Process Operation
- Technology and (vs.) theory
- Prevailing bottlenecks

③ Capturing and representing the knowledge
- Forms of knowledge and modelling approaches

④ Model-based and Hybrid methods for process monitoring and control
- Application to industrial batch processes

⑤ Some concluding thoughts
- The Human factor - investment, knowledge and industrial structure

Progress in Computer-Aided Process Operation

About the (old) gap between theory and practice

- ABOUT the application of advanced control techniques in the development of new or improved forms of process operation in the (bio)chemical industries -

How successful have they been over the last 30 to 50 years?

- ABOUT heuristics and decision-making based on rules of thumb

Have they been high-valued techniques in industrial practice throughtout the years ?

Should we value this type of knowledge for process control?

Computer-Aided Operation of Chemical and Biochemical Processes

Progress in Computer-Aided Process Operation

About the (old) gap between theory and practice

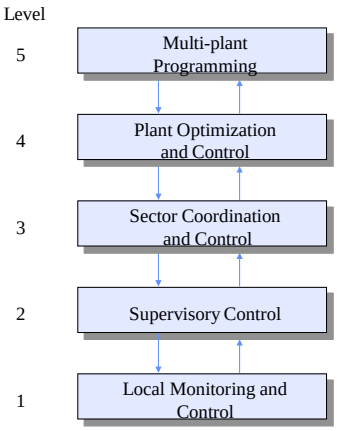
The development of new or improved forms of process operation is only successfully achieved when

It is possible to match theoretical innovation with the technology available for implementation at industrial scale

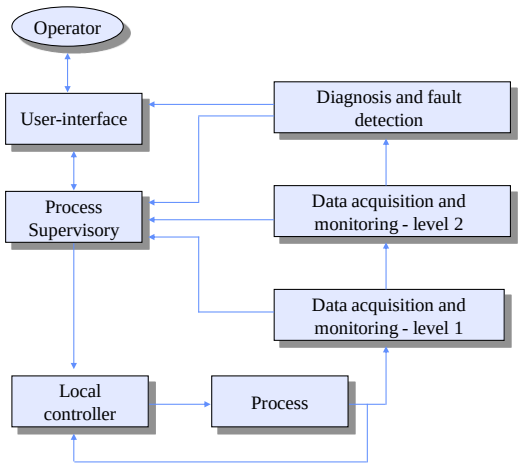
Advances in digital technology
paved the way for a new area of interest

Computer-Aided Process Operation

Computer-Aided Process Operation



Computer-Aided Process Operation
Monitoring, Diagnosis and Control



Progress in Computer-Aided Process Operation
I - Industrial control systems

- A landmark in the history of CAPO has been reached at the close of the eighties

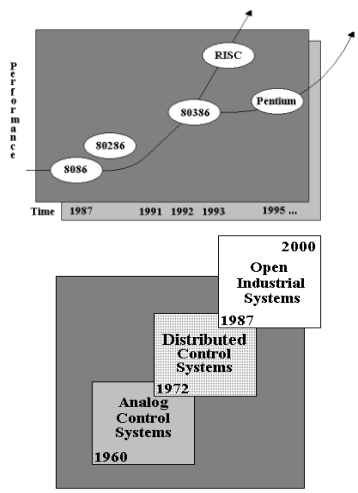
- Nowadays, control systems suppliers offer open architecture, standard operating systems and employ standard communications protocols, allowing -

  - programming with high level languages

  and

  - integration of USER-TAILORED applications

Evolution in Computer Control Systems and Control Systems Architectures



Progress in Computer-Aided Process Operation
II - Process measurements (I)

- Sensors and analytical instruments are the primary elements for process monitoring
  - In spite of the observed progress in measurement technology -

> To a large extent the technological **bottleneck** is in process measurements

At present -

- indirect measurements are still required for important properties.

Serving as example, not yet achieved -

- reliable direct measurement of crystal size distribution in industrial crystallisation

or

- measurement of biomass in fermentation processes

Progress in Computer-Aided Process Operation
II - Process measurements (II)

A topic in the front line of concern is that of -

- monitoring the behaviour of internal process variables which define the so-called process state and for which direct measurements are either -
  - not available,
  - difficult,
  - expensive,
  - or inaccurate

Issues on Computer-Aided Process Operation

OR

Galileo Revisited

☞ **~ 400 years ago, Galileo Galilei (1564-1642) -**

> "Measure what is measurable and make measurabale what is not so",

Quoted in I. Gordonand and S. Sorkin, *The Armchair Science Reader* (New York, 1959)
'Quotations by Galileo Galilei' in http://www-groups.dcs.st-nd.ac.uk/~history/Quotations/Galileo.html

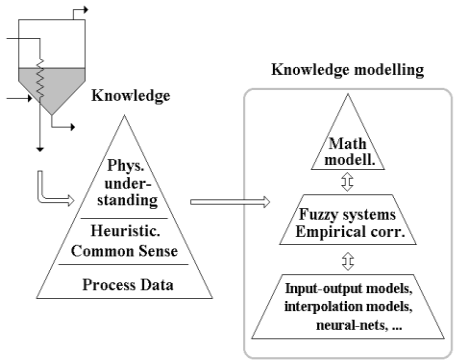
Progress in Computer-Aided Process Operation
III - Towards model-based methodologies

☞ **Re-thinking of concepts on capturing and representing process knowledge**
- What knowledge is available ?
- How can such knowledge be captured and used ?

☞ **Employing Knowledge Engineering approaches**

☞ **Employing hybrid approaches -** Combining different forms of knowledge through some (more or less) 'fuzzy' decisions
- Mechanistic models
- Empirical models
- Artificial neural networks
- …..

Capturing and representing process knowledge
I - Forms of knowledge



(From Lübbert et al. (1994))

Capturing and representing process knowledge
II - Modelling approaches (I)

- Mechanistic (first principles) models

$$\frac{d\xi}{dt} = r(\xi) - D\xi + F - Q(\xi)$$

- Input-output (stochastic) models

$$A(q^{-1})\, y(t) = B(q^{-1})\, u(t) + C(t)\, \omega(t)$$

where

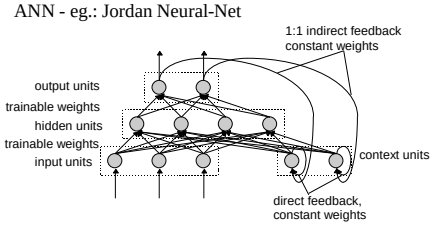
$$q^{-1}\, y(t) = y(t-1)$$

e.g.: Level control (h) with Outlet Flowrate (Q)

$$\hat{h}_k = \sum_{i=1}^{2} a_i\, h_{k-i} + \sum_{j=1}^{2} b_j\, Q_{k-j}$$

Capturing and representing process knowledge
II - Modelling approaches (II)

- AI approaches
  - ANN - eg.: Jordan Neural-Net



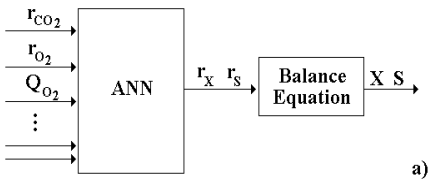
  - Fuzzy models - namely for defining relative weights of competing models

Capturing and representing process knowledge
III - Knowledge integration (I)

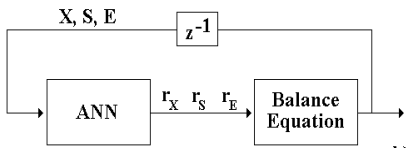
- **Hybrid Modular Structures**
  - **Aim at integration of Mechanistic + ANN and/or Fuzzy and/or RTKBS**
  - **Capturing hidden knowledge while avoiding violation of 'first principles'**
  - **Modular complementary**
    - Different types of knowledge focusing different process sub-systems
  - **Modular competitive**
    - Different sources and kinds of information for a process sub-system

Capturing and representing process knowledge
III - Knowledge integration (II)

Hybrid Modular Complementary Structure for fermentation processes



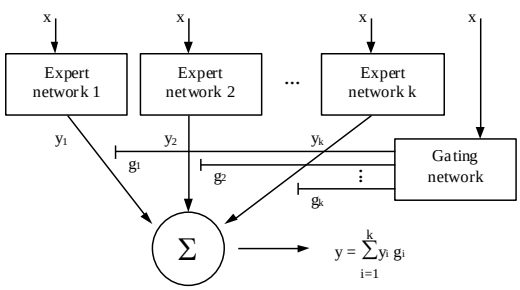
a)



b)

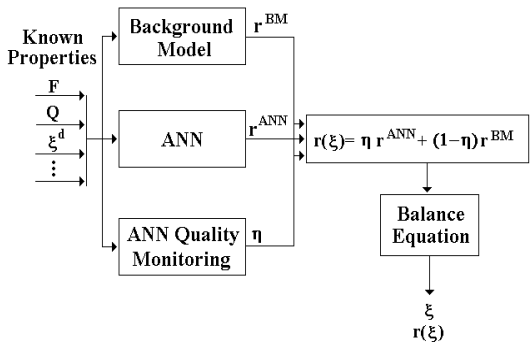
Capturing and representing process knowledge
III - Knowledge integration (III)

Hybrid Competitive Structure



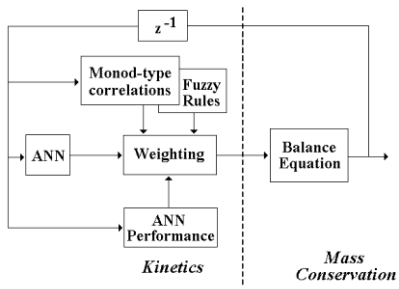
Capturing and representing process knowledge
III - Knowledge integration (IV)

Competitive + Complementary Structure for fermentation processes



Capturing and representing process knowledge
III - Knowledge Integration (IV)

Competitive + Complementary Structure for fermentation processes



Progress in Computer-Aided Process Operation
IV - Process monitoring

- Efficient standard distributed data acquisition systems for direct measurements

- Inferential measurement through Software Sensors -

´Software Sensors´ should be seen as a method by which with a minimum number of direct measurements we are able to fully describe the process state at any point of operation.

- Software Sensors can based on -
  - Mechanistic models
  - Artificial neural networks
  - Hybrid models

Software sensors and on-line state estimation
I- based on mechanistic models

① Often ´software sensors´ consist only in the manipulation of simple algebraic relationships.

That is the case for supersaturation in crystalization processes.

② In other instances, the ´sensor´ requires the use of the full deterministic model.
  - Usually one should look for some form of transformation which eliminates the ´less accurately known´ terms in the model.

Invariably these are ´kinetic rate´ terms

Software sensors and on-line state estimation
II- based on ANN or Hybrid approaches

① In other cases 'black-box' approaches are employed.

This raises major questions of confidence on results outside training areas

④ Hybrid solutions envolving mechanistic models and ANN may represent a good solution for the applied problem

Capturing hidden knowledge and avoiding violation of first principles

Some concluding thoughts (I)

The Human factor as a limiting step in the pace of development

- Cost investment sometimes difficult to justify in the short-term
- Lack of human expertise
- Need for organizational changes in the production teams

Decision for investment often based on management's vision and strategic perspectives -

What future without technological evolution at production level ?

Human attitude towards investment
It is never the right moment for investment!

- If the moment is favourable...,
- If customers are happy with our products...,
- If business is lucrative...,

☞ Why should we take risks, waist time and money in strange technologies...!?

- When crisis brake,
- With the house in flames,

☞ We cannot think of anything else, but saving our skin...!

Never do Today what you can do Tomorrow!!!

Some concluding thoughts (II)

Lack of human expertise

☞ A major role to be played by Universities in preparing today tomorrow's production directors !

☞ After all, just a natural evolution in know-how required

- the pneumatic systems engineer of the 50's
- the electronics engineer of the 70's,
- the digital systems engineer of the 90's,

The process systems engineer of the 00's

Some concluding thoughts (III)

- Today, the technological conditions are here, for bringing the theory into practice
- Difficulties in industrial operation are mainly related to -
  - Process measurements
  - (the lack of) Human expertise in process systems engineering
- Model-based and adaptive methodologies and AI approaches will play a major role in process operation
- The job for the future has already started -
  - Re-thinking of concepts on representing process knowledge
  - Bringing new methodologies into the available industrial equipment for operation in real-time.