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FDI and accommodation using NN Based Techniques

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Summary

- Detect and isolate faults in sensors, actuators and processes
- Use of massive NN based functional approximation techniques
- Use of rule based techniques
- Faults accommodation (on-line solution to plant faults)

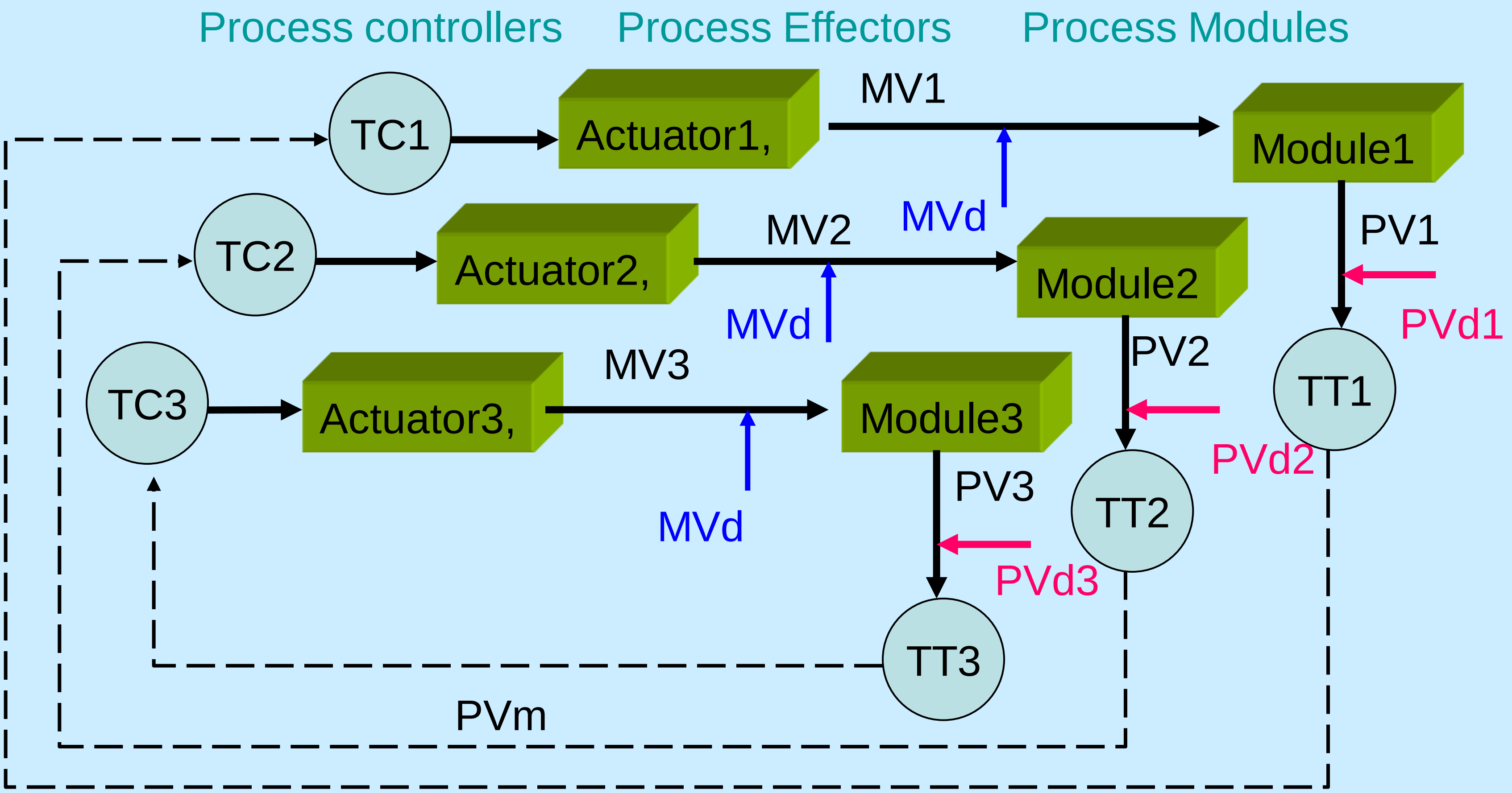
The main problems

- Lack of detectability when analytical model based techniques are being applied due to modeling errors.

- Ambiguity in fault isolation to discriminate between sensors, actuators or process faults

Block diagram of a generic Process Basic Control Structure

- The accuracy of the measurement system is relevant in process control
- Faulty sensors implies the lost of control



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Causality of the feedback control systems

In closed loop systems, signals are subjected to the causality principle. Propagation of the signals flow.

Manipulated variable

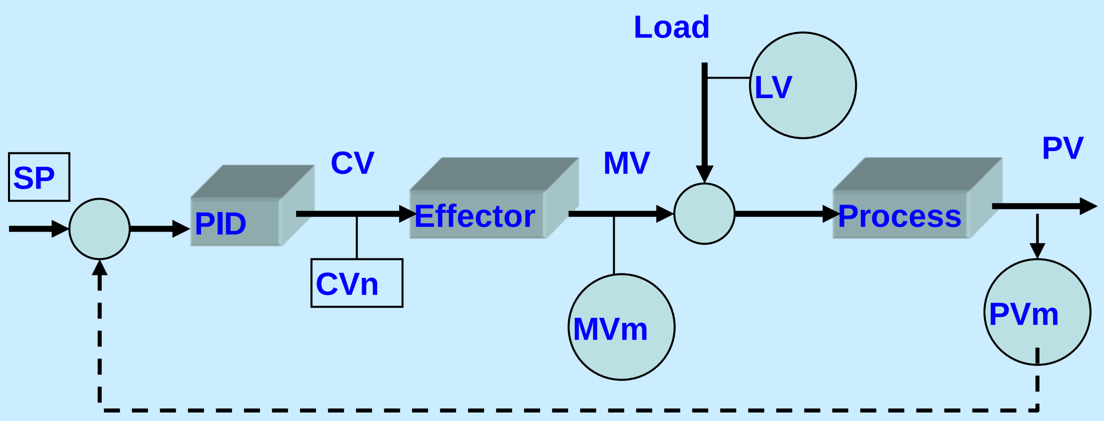
MV = f(CV, effector param)

Process variable

PV = f(MV, LV, process param.)

Measured Process variable

PVm = f(PV, PVd, sensor param.)



NN based functional approximation

Modeling technique: State variable feedback

Admitted structure for the plant modules models

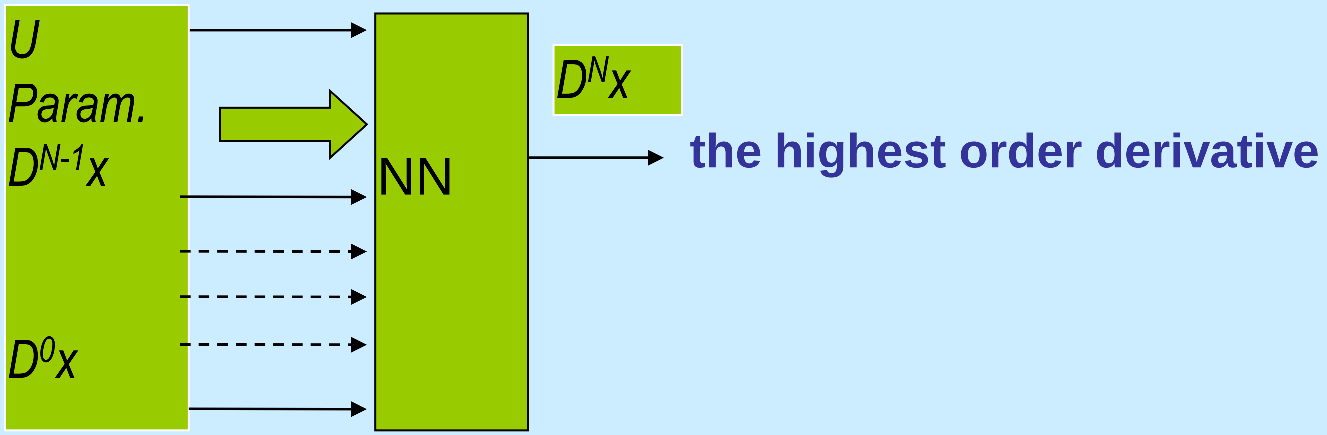
$$\dot{x} = [A]x + [B]U$$

$$y = [C]x$$

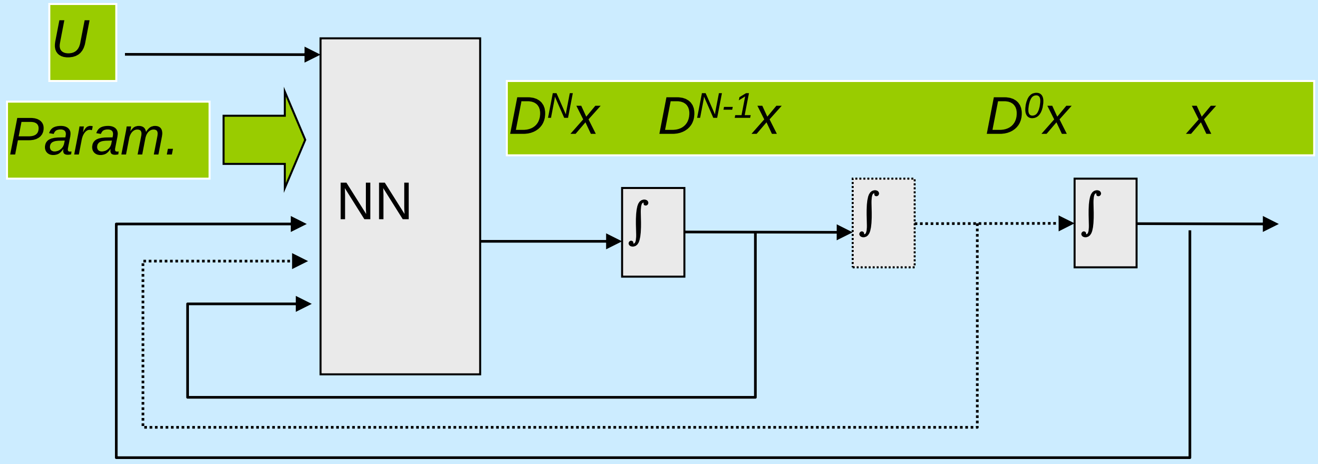
Dynamic model structure, the highest order derivative

$$D^N x = f(U, D^{N-1}x, \cdots D^0 x)$$

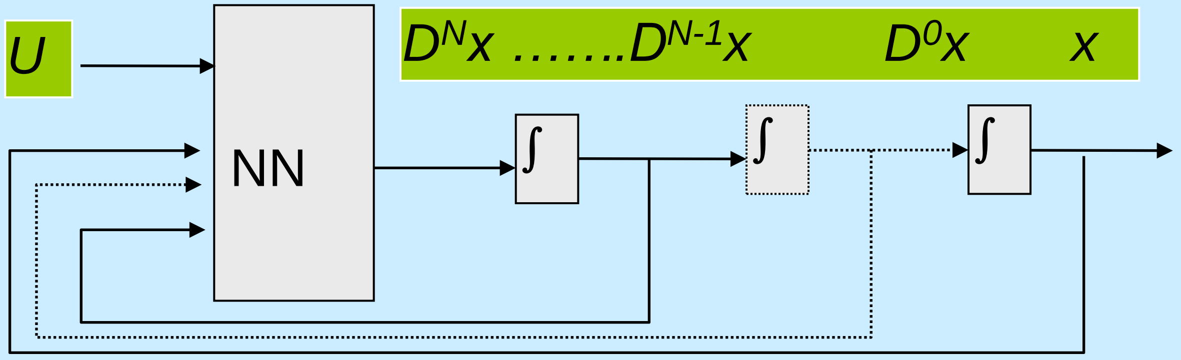
Model implementation under feeforward neural network based structure



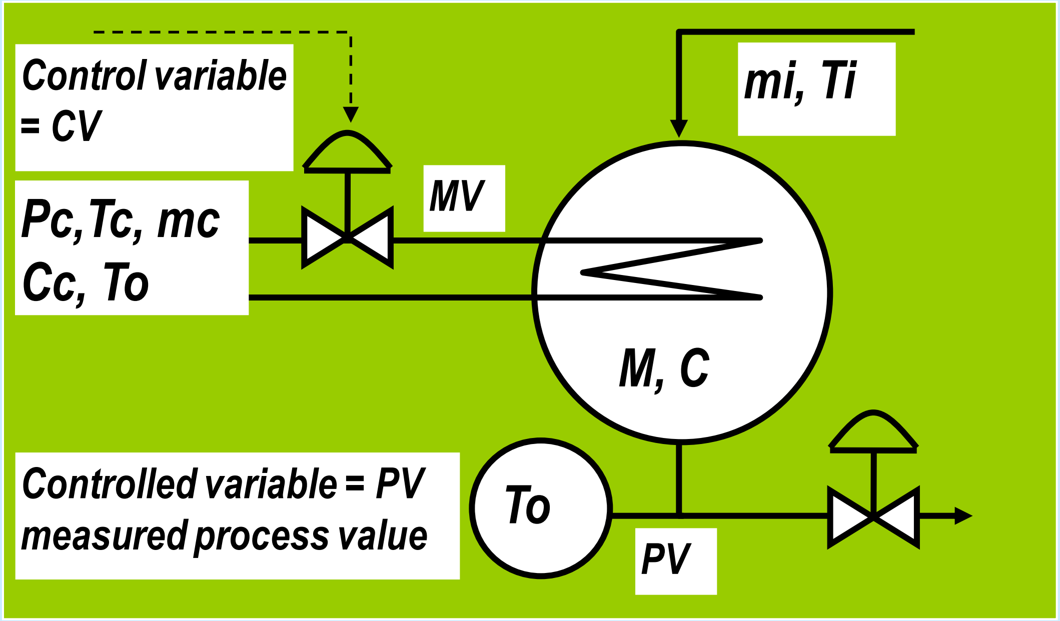
Implementation of the dynamic neural network which includes
•input/output variables,
•internal state variables and
•process parameters



Simplified model when plant parameters are constant



The supervised heat exchanger pilot plant



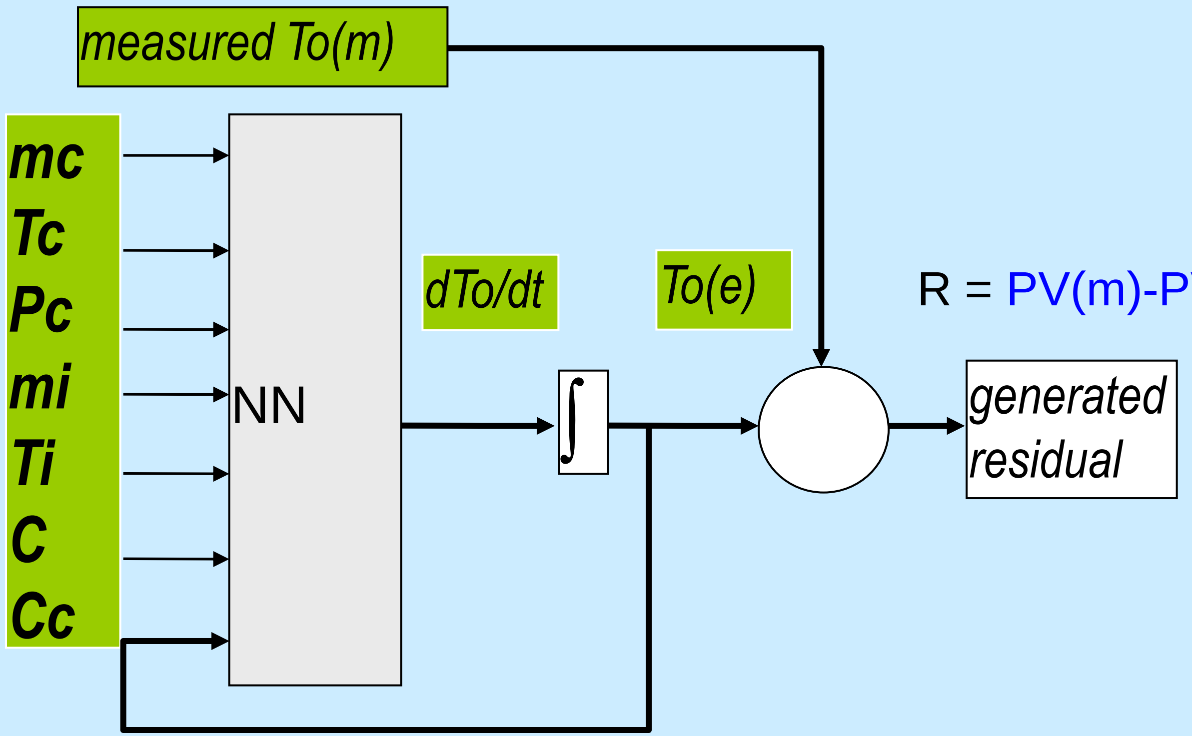
The supervised heat exchanger process scheme

The notation used in the heat exchanger NN based model

Process parameters	*Symbols*
Heating fluid mass flow rate generated by the controller	*mc*
Heating fluid input temperature	*Tc*
Heating fluid input pressure	*Pc*
Heated fluid mass flow rate	*mi*
Heated fluid Inlet temperature	*Ti*
Heated fluid specific heat	*C*
Heated fluid temperature	*To*
Heating fluid specific heat	*Cc*

The residual generation task:

Measured process variable is compared with estimated process variable.



R = PV(m)-PV(e) = To(m) – To(e)

Resulting residuals are evaluated by comparing its actual value with a tolerance value

Control and supervision goals

The main control objectives consists in achieving accurately an output process value (temperature *To*) under common practical constraints and limitations.

The supervision objectives consists in

- detect and isolate plant faults,
- performing plant accommodation tasks and subsequent control reconfiguration to satisfy the control objectives.

The ambiguity of FD by residual evaluation

A residual *R* may exceed the limit value when changes in

- plant parameters,
- or sensor malfunction
- or both events are present.

Conflict resolution due to several simultaneous changes

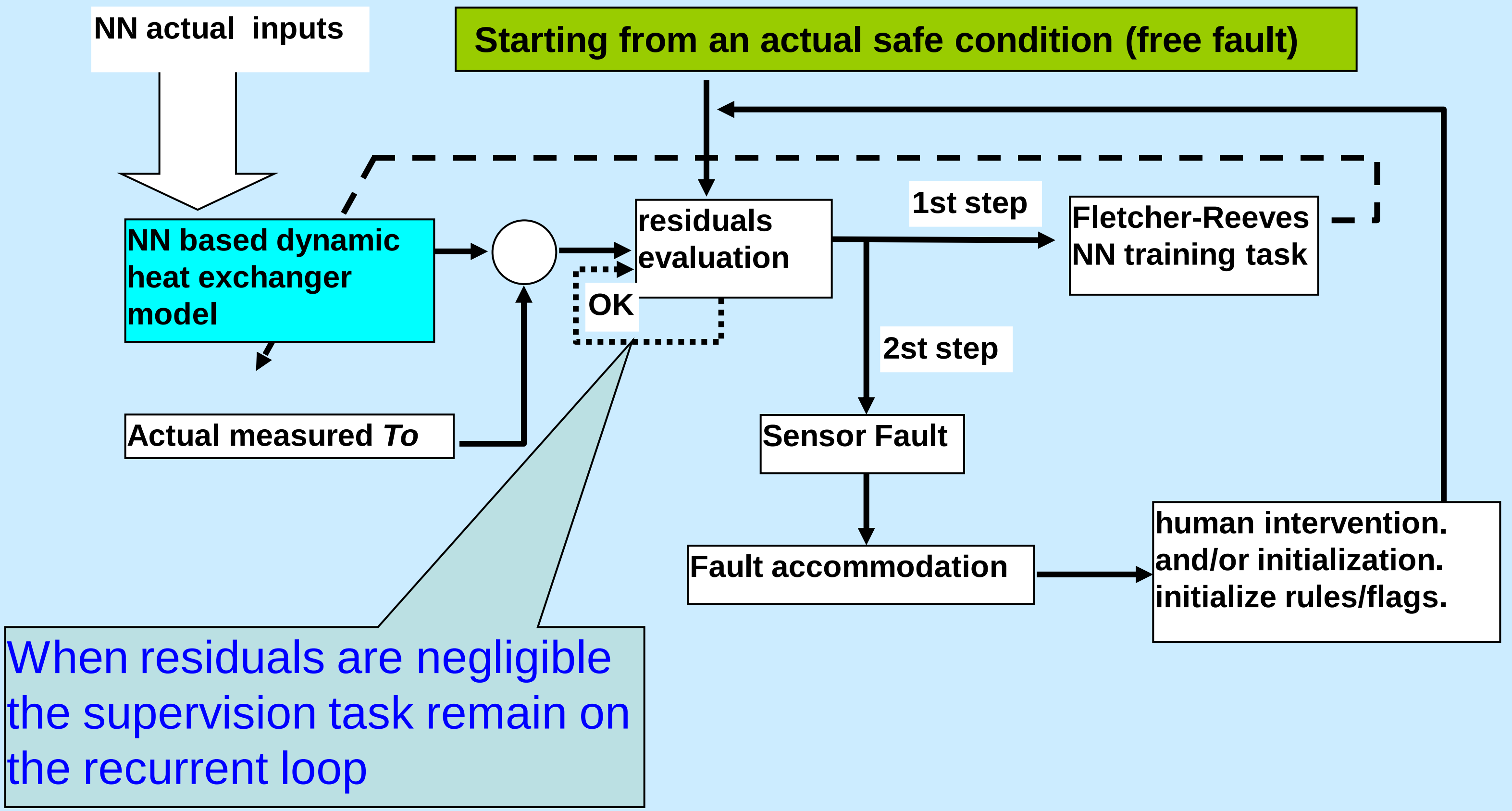
Because of the possibility of the occurrence of both events simultaneously, a rule based strategy to solve the given conflict must be applied.

Enabling the Supervision Task

To enable the supervision task, the proposed strategy checks the changes in plant parameters by means of residuals evaluation at the first supervision step.

If a residual exceed the maximum admitted tolerance *Tol*, then model parameters needs to be adjusted.
It is necessary to update the NN based model to the actual dynamic condition by applying a NN training session with the most recent good historical data.

and if residual excess is *persistent* then such symptom means that a fault in the measuring system is present.


NN actual inputs
Starting from an actual safe condition (free fault)
NN based dynamic heat exchanger model
residuals evaluation
1st step
Fletcher-Reeves NN training task
OK
2st step
Actual measured To
Sensor Fault
Fault accommodation
human intervention. and/or initialization. initialize rules/flags.
When residuals are negligible the supervision task remain on the recurrent loop

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Applying Physical redundancy

Using only a sensor to measure the process value:

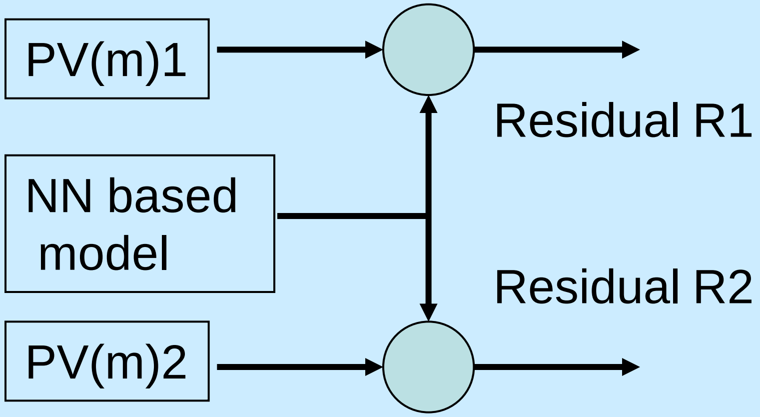
it is not possible to decide deterministically if a fault is due to the sensor or the process.

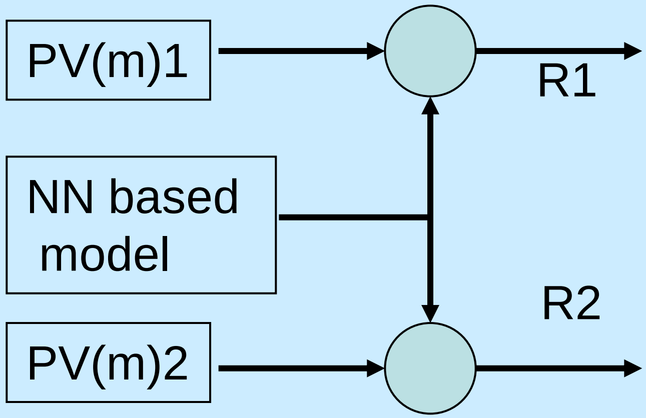
Using two sensors to measure the process value:

it is possible to decide deterministically if a fault is due to the sensors or process,

although we can not decide which sensor fails.

Using historical data sometimes may be possible to know which sensor fails





The Supervision Enabling Task by residuals management with redundancy

Sensors test

IF (R1 OR R2) > Tol AND R1 ≠ R2 THEN

IF PV(m)1 ≠ PV(m)2 AND R1 ≈ 0 AND R2 > Tol →

Adjustment of PV(m)2

IF PV(m)1 ≠ PV(m)2 AND R2 ≈ 0 AND R1 > Tol →

Adjustment of PV(m)1

ELSE Process changes test

END_IF

Process changes test

IF PV(m)1 ≈ PV(m)2 AND (R1 OR R2) > Tol →

NN model adjustment required

Fault accomodation **must be applied when the conditions are met:**

IF PV(m)1 ≠ PV(m)2 AND R1 ≈ 0 AND R2 > Tol → Adjust PV(m)2

IF PV(m)1 ≠ PV(m)2 AND R2 ≈ 0 AND R1 > Tol → Adjust PV(m)1

Accommodation fault Task

As consequence of the persistent residual due to the measuring system fault, a fault accommodation technique is to be applied based on the compensation of the estimated measuring signal drift error.

Since the residual *R* is defined as (*To(m)* – *To(e)*), the accommodation technique is implemented under the following rule:

IF *R* > *Tol* THEN applied feedback control signal is (*To(m)* – *R*), and the closed loop control system is performing right.

IF *R* > *Tol* → apply the feedback control signal:

(*To(m)* – *R*) instead of To(m)

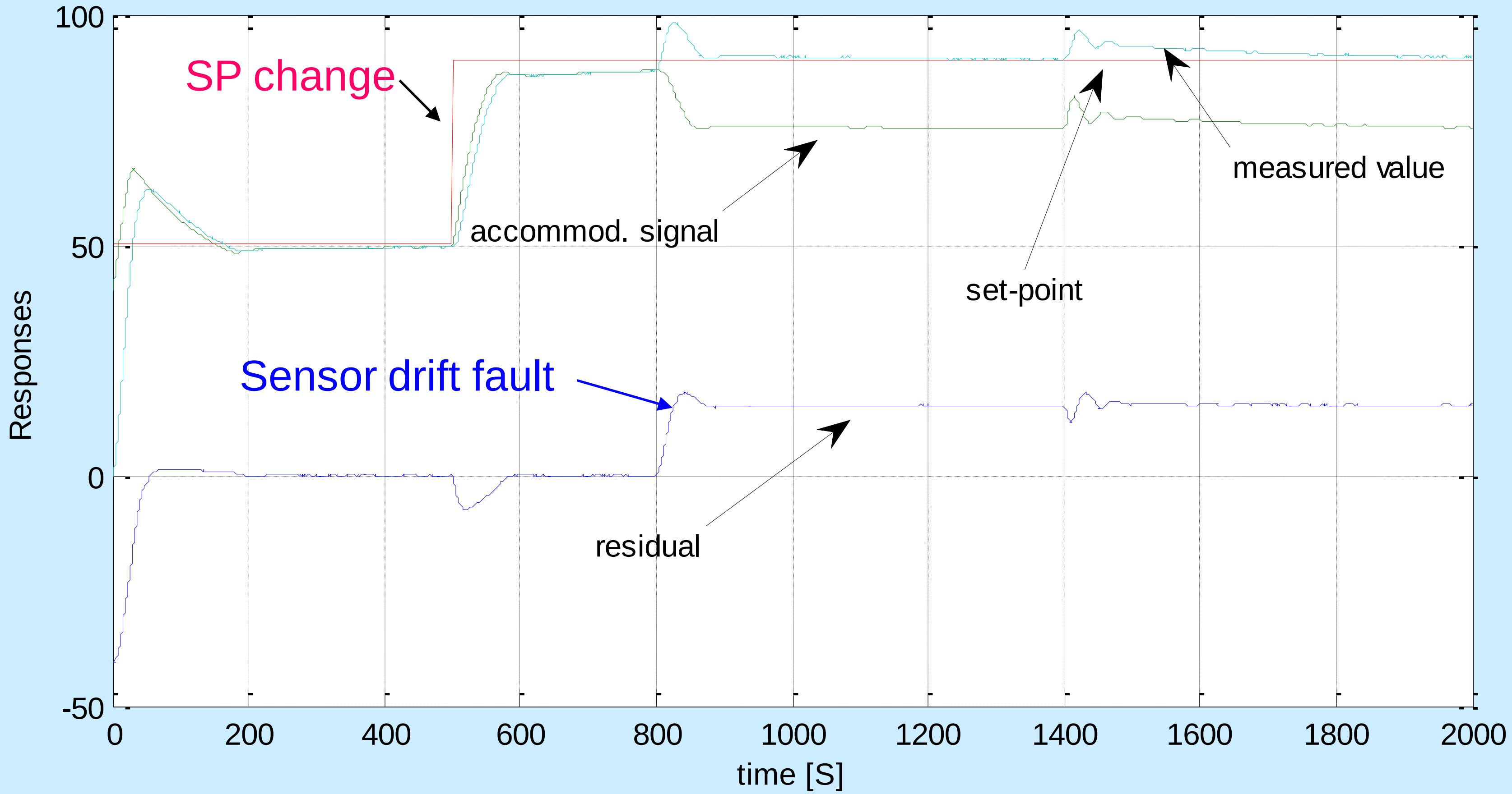
Proof of the Accommodation fault strategy

To(m) – R = To(m) – (To(m)-To(e)) = To(e).

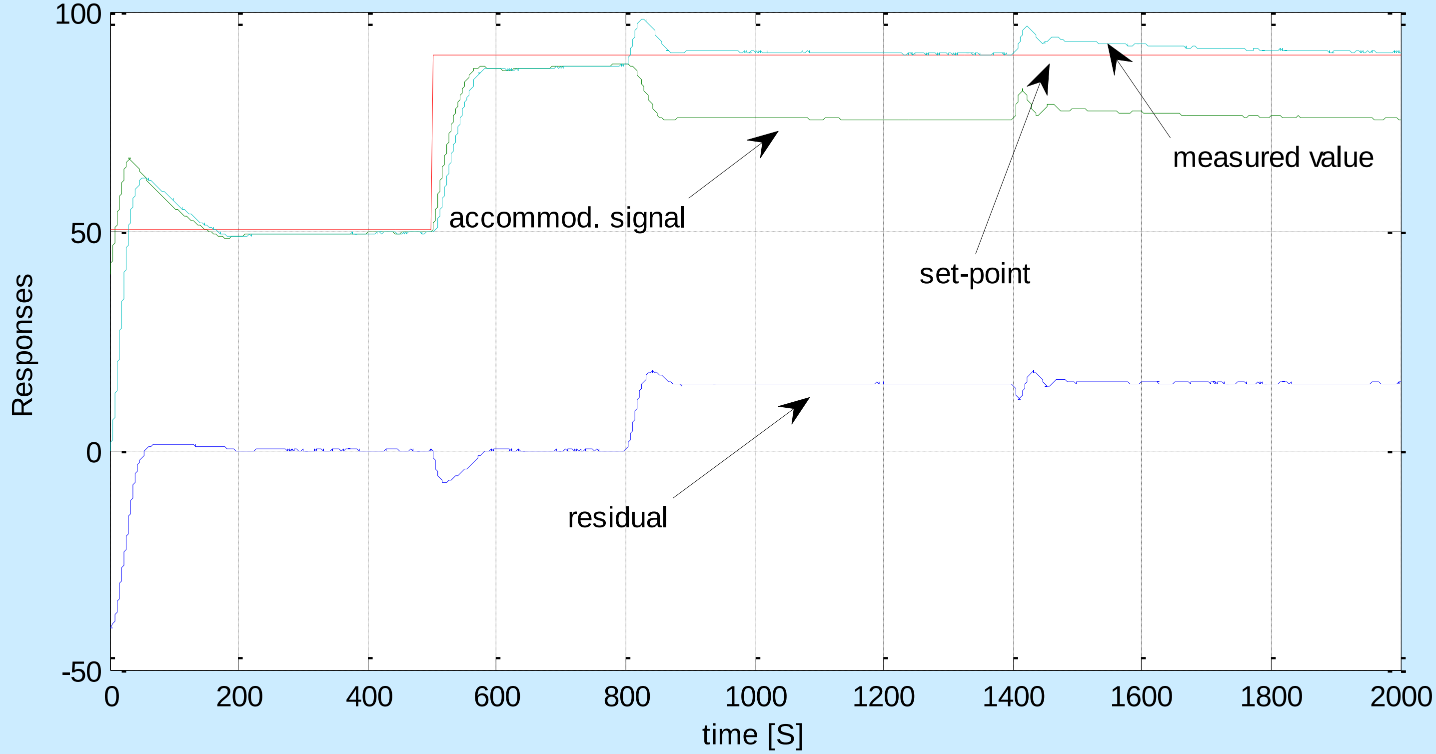
which means that To(m) ≅To(e)

Such correction strategy ensures that the feedback signal is the true value even under process value sensor malfunction

The time domain responses of the supervisor mechanism operating in fault detection and isolation mode



- Correct operation before 800 sec.
- At 800 sec. **drift fault** type of 20% increase; control error increase and the feedback **controller tray to avoid the control error**.
- Consequently the measured value reach the set-point value. But PV is out of SP



The supervision system has generated a relevant residual, which is responsible for advising of a problem that should be solved.

Since the decision making strategy is programmed to notify by means of a warning to the human operator and not to correct the fault in such a case, the supervision system finished the cycle and jumps to the initialization task.

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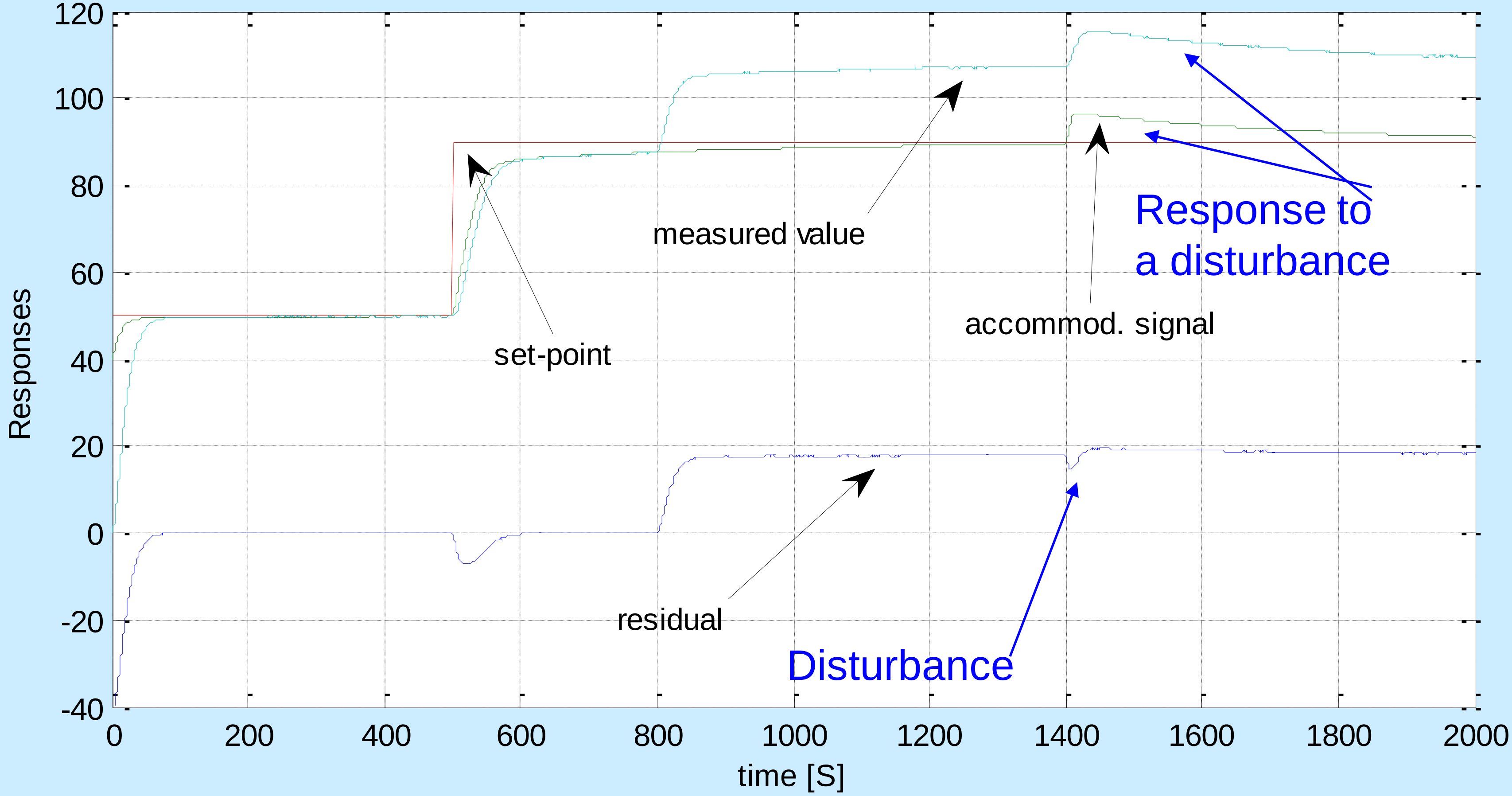
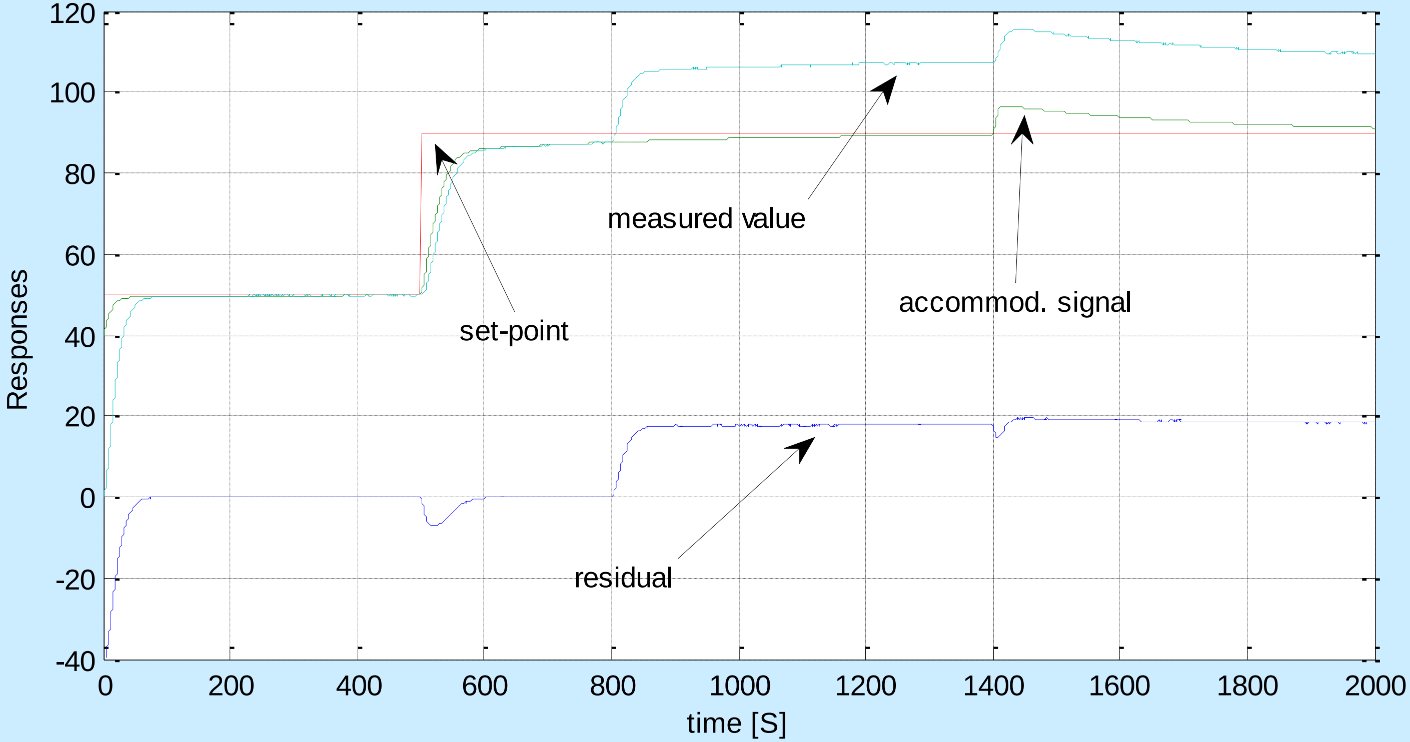
The time response of the supervisor test operating in fault accommodation mode





After the fault is detected, the feedback controller tray to avoid the control error but the measured value doesn’t reach the set-point value.

This is due to the effect of signal accommodation to a value such that the process value is reaching the set-point value.

Nevertheless the supervision system has generated a relevant residual, which is responsible for notifying of the presence of a problem that is being eventually solved.

Since the decision making strategy is programmed to

- notify the operator
- correct the fault (Accommodation).

Supervision task continues

When elapsed running time reached 1400 sec., a disturbance entered the heating process, which can not be completely cancelled by the generated accommodation signal during a short period of time.

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Conclusions:

A supervision strategy to detect, isolate and accommodate faults in closed loop control systems on the basis of a dynamic NN based modeling technique has been implemented on a heat exchanger.

A FDI strategy based on the combination of a rule based scheduler with a residual generator achieved by dynamic NN based models has been applied.

A decision making strategy on the basis of system accommodation and control system reconfiguration has been successfully applied.

Experiments show that the detection of a fault due to a sensor drift as well as some process parameter variation may be efficiently detected and accommodated.

Since the NN based model must be initialized at the beginning of every supervision task, the initialization value must be measured from the actual real time value.

Such premise requires the condition of a correct measuring system at the starting instant.

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Serious disadvantages

The implemented supervising system needs to be updated when parameter changes have occurred by training the applied neural networks.
This characteristic is a serious drawback since the plant must be forced to an off-line condition, which has a direct repercussion or influence on the system productivity.

Finally a relevant disadvantage of the applied methodology is the impossibility to isolate faults when more than a fault is affecting the plant due to the ambiguity of the processed data.

A technical solution to such problem is the application of analytical and/or physical redundancy which increases dramatically the installation and maintenance costs in the case of physical redundancy