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Tolérance aux fautes par une approche superviseur: gestion du couplage FDI-FTC

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Outline

- **Preliminary**
- **A brief state-of-art**
  - Passive approaches
  - Active approaches
  - Closing words -> Limitations
- **Supervisory FTC with mutual perf. optim.**
  - Theory and principles
  - Overall stability
  - Optimization issue
- **Academic illustration**
- **Closing words**

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Preliminary 1/2

- **Fault Tolerant Control (FTC)** strategies are meant to manage faulty situations by maintaining overall system stability and acceptable performances.

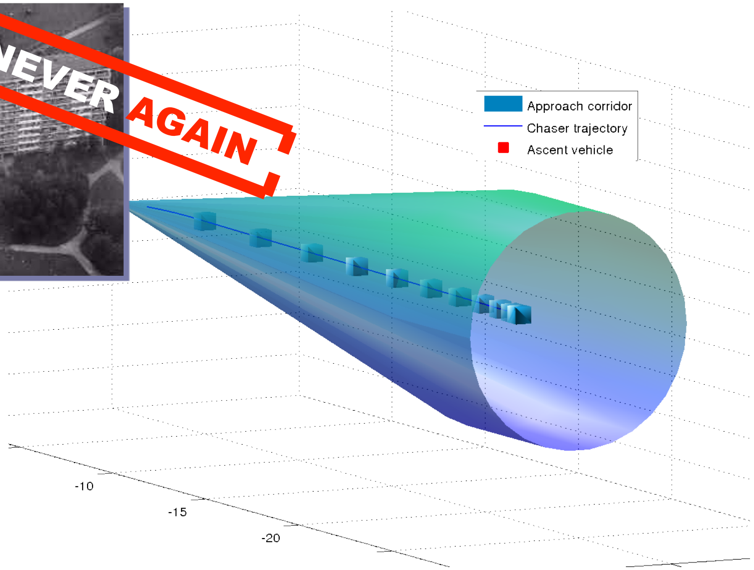
- **Fault tolerant control** (FTC) deals with a concept for handling faulty situations by suitable reconfiguration of the control laws
- It is fundamentally **a control problem** (and nothing else)

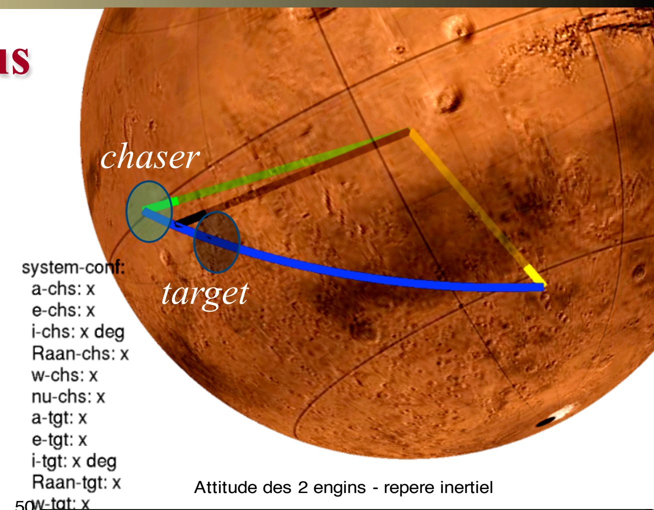
  \- at least, one fault occurs in the system (of course, these faults have to be diagnosed)

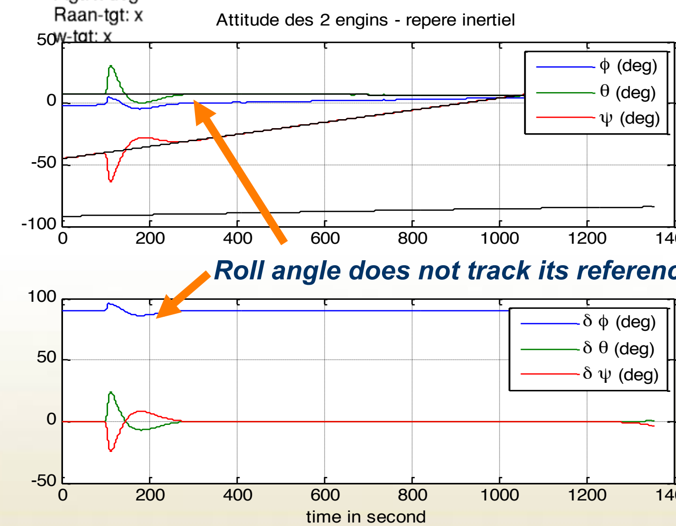
  \- **performances achieved by the already in place control laws are no more satisfactory**

Preliminary 2/2

- **An example from space: rendezvous**







One thruster is out of order*, i.e. the fault is still occurring.*

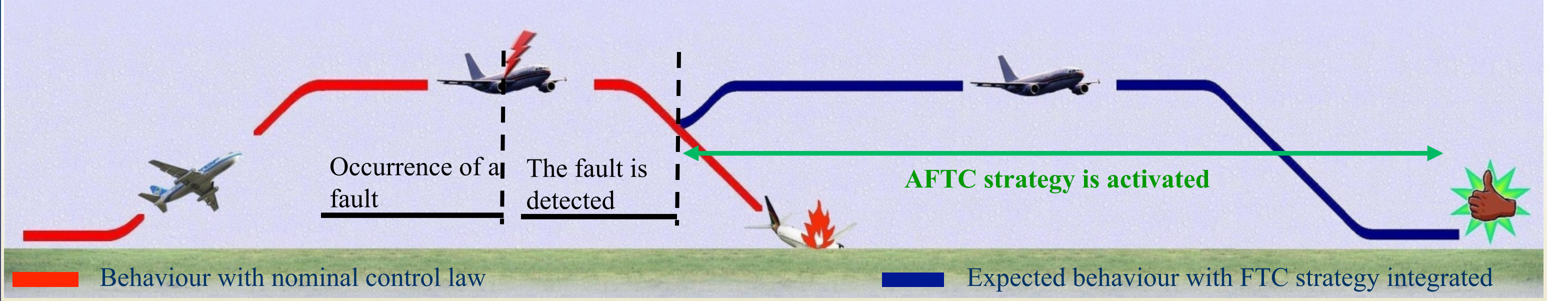
⇒ ergol over-consumption

⇒ BUT the mission is not in danger !

- **Preliminary**
- State-Of-Art
- Supervisory FTC
- Example
- Closing words

State-of-art 1/4

- **Two main approaches:** Different controller architectures for FTC have been suggested in the literature, see (Aström K et al, 2000; Zhang & Jiang, 2008; Noura et al, 2009 for good surveys)
  - **Passive Fault-Tolerant Control systems (PFTC):**
    - nothing else than robust control approaches against pre-specified faults
    - has limited fault-tolerant capabilities
  - **Active Fault-Tolerant Control systems (AFTC):**
    - no degradation of fault-free operating mode
    - principle: **1) Detect the fault event (FDI issue);**
      2) Activate the fault compensation mechanism (switching logic usually)
      3) Reconfigure the control laws (FTC issue) or mission objectives (FTG issue)



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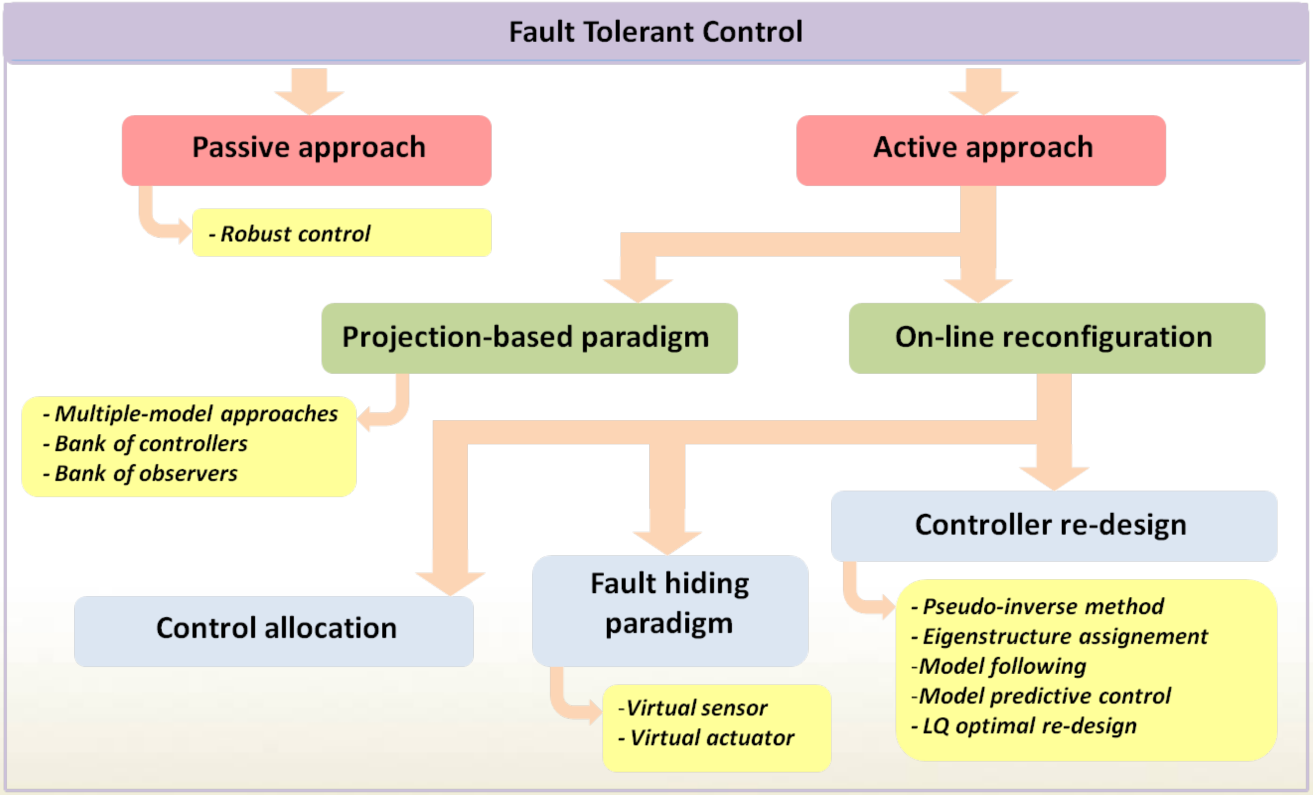
State-of-art 2/4

- **Classification:** Inspired by Lunze et al 2006 and Zhang & Jiang 2008



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State-of-art 3/4

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- **Closing words of State-of-art: AFTC limitations**

FDI unit

Activation mechanism of fault compensation

Fault tolerant controller

must work in harmony to safe issues.

- **Open problem:** Guaranteeing stability and performances of the overall fault tolerant scheme taking into account the FDI, the switching and the re-configuration mechanisms, is not considered. In practice, coupling properties are studied by means of a Monte-Carlo campaign.

- FDI unit design
- Quantification of its performance levels (robustness, sensitivity,...)

Perfect interactions !!???

- FTC unit design
- Quantification of its performance levels (stability, acceptable damping ratio, ...)
- Design of reconfiguration mechanism
- Quantification of the performance levels (stability is preserved?, ...)

As a direct consequence, even if the stability can be achieved, **there does not exist any proof of global optimality of the FTC scheme** since the controllers and the FDI/fault estimation algorithms are designed separately.

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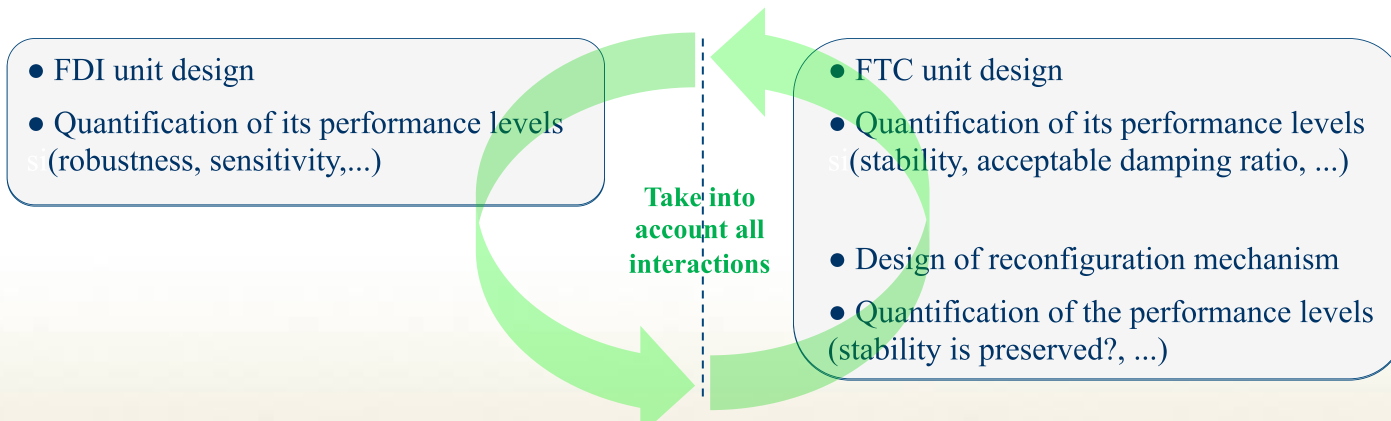
State-of-art 4/4

- **Some examples:**
  - High sensitivity of the residual to fault is obtained. However, the detection delay can be too long to have safe recovery actions;
  - Good FDI performances (sensitivity, robustness, small detection delay) are obtained but the activation mechanism introduces undesirable transients (when FTC part is activated) leading to inappropriate behaviors (on aircraft, nuclear plants, ...);
  - ...
- **A possible unified context:**

Supervisory control theory
(Liberzon, 2003)



Supervisory FTC approach with mutual performance optimization

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Supervisory FTC with mutual perf. 1/11

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- **Objectives:**
  - **Formal stability proofs are established** for the overall FTC scheme taking into account the plant model switching, the control reconfiguration switching and the influence of uncertainties and unknown inputs.
  - The method allows **to design both the FDI and FTC units taking into account their coupling**. The method allows to derive a FDI and fault tolerant controller scheme with guaranteed stability and well established performance in terms of robustness, fault detection and tolerance.
  - It is proved that the global **stability of the control law is preserved even if the FDI scheme fails** to identify the correct fault. In this case, there may exist a system chattering effect that can be reduced by choosing some adequate parameters.

A great advantage for space missions since it is not necessary to switch off the diagnosis and the tolerance algorithms, global stability of the GNC being formally proved in both fault free and faulty situations.

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Supervisory FTC with mutual perf. 2/11

- **Theory & principles:** D. Efimov, J. Cieslak, D. Henry, Supervisory fault-tolerant control with mutual performance optimization, *Int. J. Adapt. Control & Signal Proc.*, 2012

- System model:
$$\dot{\mathbf{x}}_p = \mathbf{A}_p\mathbf{x}_p + \mathbf{B}_p\mathbf{u}_p + \mathbf{G}_p\mathbf{d}$$
$$\mathbf{y}_p = \mathbf{C}_p\mathbf{x}_p$$

- Assume a already in-place nominal control:
$$\dot{\mathbf{x}}_c = \mathbf{A}_c\mathbf{x}_c + \mathbf{B}_c\mathbf{y}_p$$
$$\mathbf{y}_c = \mathbf{C}_c\mathbf{x}_c + \mathbf{D}_c\mathbf{y}_p$$

Then, considering actuator and component faults:
$$\dot{\mathbf{x}}_p = (\mathbf{A}_p + \Delta\mathbf{A}_i)\mathbf{x}_p + (\mathbf{B}_p + \Delta\mathbf{B}_i)\mathbf{u}_p + \Delta_i + \mathbf{G}_p\mathbf{d} \qquad i = \overline{1,N}$$
$$\mathbf{y}_p = \mathbf{C}_p\mathbf{x}_p$$

- matrices ΔA_i, ΔB_i multiplicative faults

- vectors Δ_i additive faults.

- Preliminary
- State-Of-Art
- **Supervisory FTC**
- Example
- Closing words

- **Objective:**

The goal is to design the control signal u in parallel with the nominal controller (A_c, B_c, C_c, D_c) so that
$$\mathbf{u}_p = \mathbf{y}_c + \mathbf{u}$$

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Supervisory FTC with mutual perf. 3/11

- **Theory & principles:** D. Efimov, J. Cieslak, D. Henry, Supervisory fault-tolerant control with mutual performance optimization, *Int. J. Adapt. Control & Signal Proc.*, 2012

With this new (tolerant) control law:

$$\dot{\mathbf{x}} = \mathbf{A}_i\,\mathbf{x} + \mathbf{B}_i\,\mathbf{u} + \Delta_i + \mathbf{G}\,\mathbf{d}$$
$$\mathbf{y} = \mathbf{C}\,\mathbf{x} \qquad i = \overline{1, N}$$
$$\mathbf{x} = [\,\mathbf{x}_p^T\ \mathbf{x}_c^T\,]^T \in R^n$$
$$\mathbf{y} = [\,\mathbf{y}_p^T\ \ \mathbf{x}_c^T\,]^T \in R^q$$

A family of linear systems with the index $i \in I$

Adding the switching signal $i: R_+ \to I$ that is in charge to select the controller i (prior designed) associated to the system mode i, the overall system can be formulated as a linear switched system

- The FTC design problem can be reformulated as a switched system stabilization problem.
- Since the N controllers are pre-designed, the approach can be classified as a part of the projection-based class and more specially as a Multiple-Model approach (i.e. behaves to the class of pre-computed FTC solutions).

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Supervisory FTC with mutual perf. 4/11

- **Theory & principles:**
  - The problem of supervisory FTC design has already been addressed in the literature (Blanke, *et al*., 1997; 2003; Boskovic and Mehra, 2002)
  - Many approaches have been applied for **independent** optimization of the fault detection, isolation and compensation systems.

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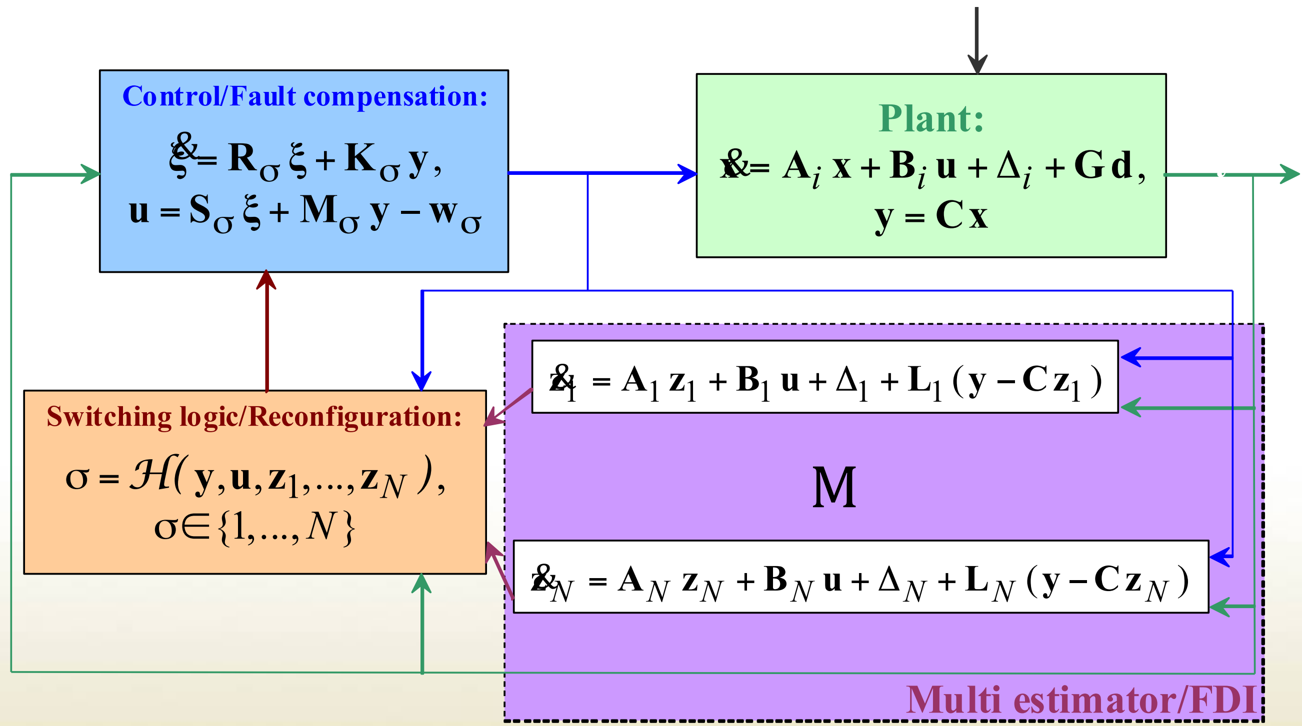
Supervisory FTC with mutual perf. 5/11

- **Structure:**
  - N controllers
  - N mode estimators (the FDI unit)
  - An activation mechanism (switching)

Assumptions:

- $\mathbf{A}_i - \mathbf{L}_i\,\mathbf{C}$ are stable
- $\mathbf{H}_i = \begin{bmatrix} \mathbf{A}_i + \mathbf{B}_i\mathbf{M}_i\mathbf{C} & \mathbf{B}_i\mathbf{S}_i \\ \mathbf{K}_i\mathbf{C} & \mathbf{R}_i \end{bmatrix}$



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Supervisory FTC with mutual perf. 6/11

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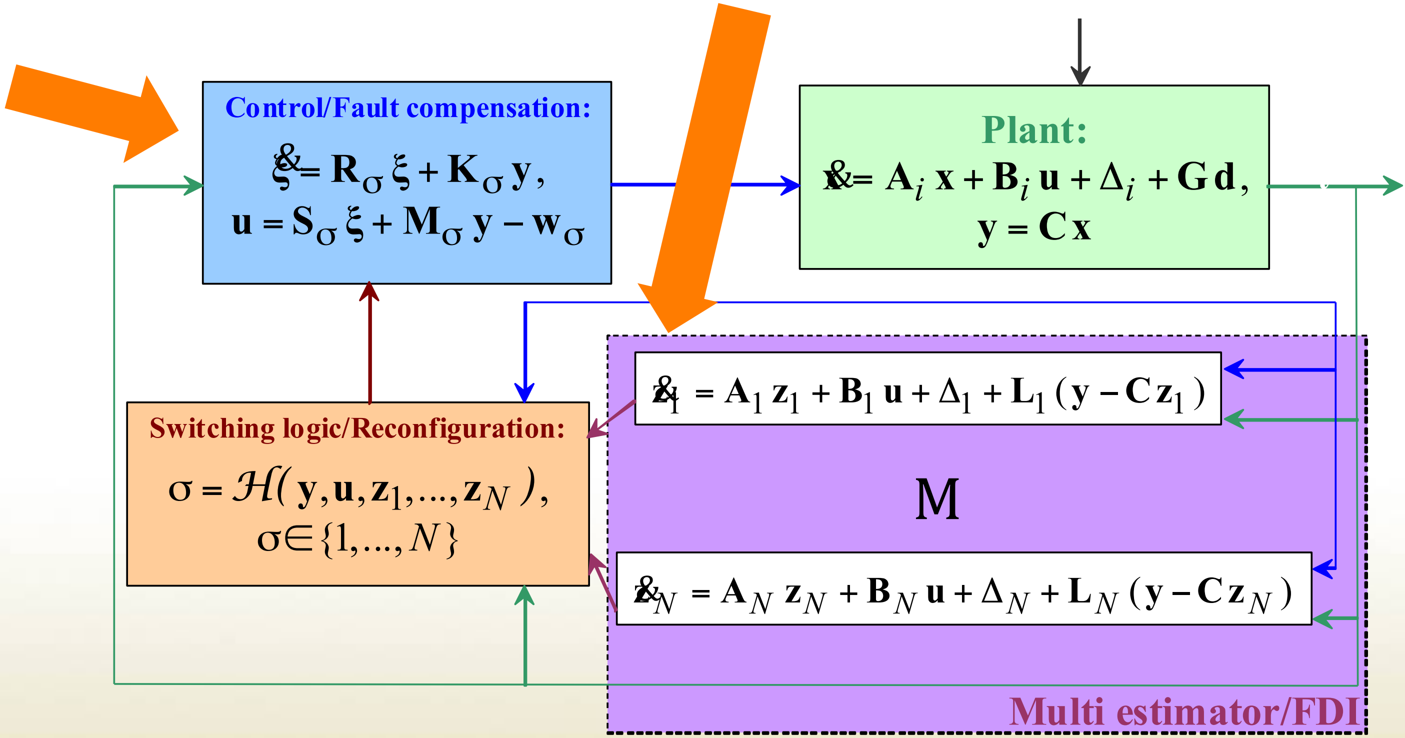
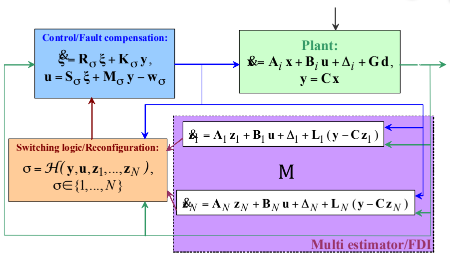
- **Structure:**

Controllers are calculated to ensure some control performance (e.g. H_∞, H2).

Observers are designed to maximize their sensitivity to predefined faults and robustness against disturbances, … in some criteria sense (e.g. decoupling, H(0), H-, H∞, H2, pole assignment …);



Supervisory FTC with mutual perf. 7/11



- **Structure:** Optimality of the subsystems does not imply the same property for the whole system.

Focus on dwell-time conditions: a mutual performance optimization can be done with minimization of the dwell-time value under FDI / control perf. constraints

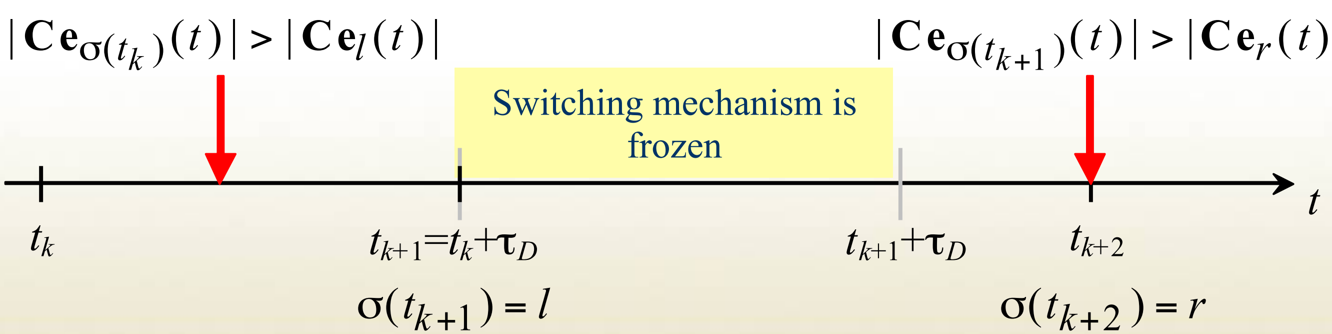
Switching logic:

$$t_0 = 0, t_{k+1} = \arg\inf_{t \geq t_k + \tau_D} \{h \,|\, |Ce_{\sigma(t_k)}(t)| > |Ce_j(t)|, j = 1, \ldots, N, j \neq \sigma(t_k)\}, k \geq 0$$

$$\sigma(t_k) = \arg\min_{1 \leq j \leq N} |Ce_j(t_k)|, k \geq 0$$

$$\sigma(t) = \sigma(t_k) \quad \text{for all} \quad t_k \leq t < t_{k+1}, k \geq 0$$

where $t_k, k \geq 0$ are instants of switches and $\tau_D > 0$ is the dwell-time constant.



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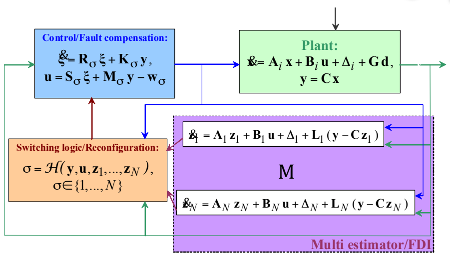
Supervisory FTC with mutual perf. 8/11



- **Structure:** *Using some linear algebra manipulations, the supervisory FTC architecture gives the following equations for*

$$\begin{cases} \dot{x} = A_i x + B_i (S_k \xi + M_k y - w_k) + \Delta_i + G_i d = (A_i - L_i C) x + B_i S_k \xi + (B_i M_k + L_i) y + \Delta_i - B_i w_k + G_i d \\ \dot{\xi} = R_k \xi + K_k y = K_k C z_k + R_k \xi + K_k C e_k \\ \dot{z}_k = A_k z_k + B_k (S_k \xi + M_k y - w_k) + L_k (y - C z_k) + \Delta_k = (A_k + B_k M_k C) z_k + B_k S_k \xi + (B_k M_k + L_k) C e_k \\ \dot{z}_j = A_j z_j + B_j (S_k \xi + M_k y - w_k) + L_j (y - C z_j) + \Delta_j = \\ \quad = (A_j - L_j C) z_j + B_j S_k \xi + (B_j M_k + L_j) y + \Delta_j - B_j w_k, \; j = \overline{1, N}, \; j \neq k. \end{cases}$$

- Consider the augmented state ζ_k :

$$\zeta_k = [z_k^T \; \xi^T \; x^T \; z_1^T \dots z_N^T] \quad k = \overline{1, N}$$

the *kth* estimator state — the *N* controller states — the *N* system states — the *N-1* estimator states

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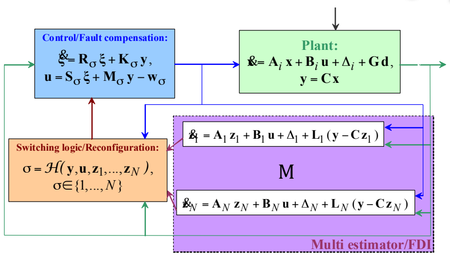
Supervisory FTC with mutual perf. 9/11



- **Structure:** (Efimov, Cieslak, Henry, 2012)

$$\dot{\xi}_k = \mathbf{W}_{k,i}\,\zeta_k + \mathbf{V}_{k,i}\,\mathbf{C}\mathbf{e}_k + \iota_{k,i} + \tilde{\mathbf{G}}_i\mathbf{d} \qquad (1)$$

where the matrix $\mathbf{W}_{k,i}$ being left block triangular with the blocks on the main diagonal $\mathbf{H}_k, \mathbf{A}_i - \mathbf{L}_i\mathbf{C}, \mathbf{A}_1 - \mathbf{L}_1\mathbf{C}, \mathbf{A}_N - \mathbf{L}_N\mathbf{C}$

Eq. (1) is stable.

- Define the augmented state: $\psi = [\xi^T \; \mathbf{x}^T \; \mathbf{z}_1^T \ldots \mathbf{z}_N^T]$

Then, there exist permutation matrices $\mathbf{T}_j$ so that $\psi = \mathbf{T}_j\,\zeta_j$

- Owing the standard results on dwell-time switched systems stability (Liberzon, 2003; Morse, 1995; Xie et al., 2001; Efimov et al., 2008) the value of τ_D be taken to satisfy:

$$\tau_D = \max_{1\le j\le N}\{-\alpha_{j,i}^{-1}\ln(\lambda\beta_{j,i}^{-1})\}$$

minimal (in norm real part) of eigenvalues of the matrix $\mathbf{W}_{j,i}$

$$\beta_{j,i} = \sup_{t\ge 0}|\exp(\mathbf{T}_j\mathbf{W}_{j,i}\mathbf{T}_j^{-1}t)|$$

A slow dynamic involves a long dwell-time

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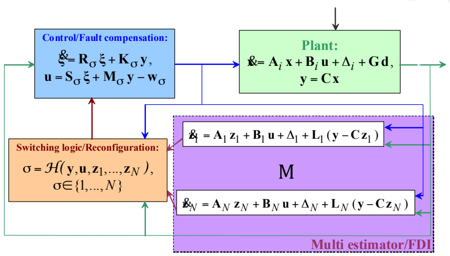
Supervisory FTC with mutual perf. 10/11



- **Stability theorem:** (Efimov, Cieslak, Henry, 2012)

Let $i(t)=const$ for all t ≥0. Then there exists τ_D such that for any $\psi(0)$ and finite $\|d\|$

$$|\psi(t)| \le \nu_i e^{-\mu_i t/\tau_D} |\psi(0)| + \upsilon_i \{\|\delta\|_{[0,t)} + \|d\|_{[0,t)}\} + \varpi_i \max_{1\le i\le N} |\Delta_i|$$

for all t ≥0 and some parameters $\nu_i>0$, $\mu_i>0$, $\varpi_i>0$ and $\upsilon_i>0$ where

$$\delta(t) = \begin{cases} C[e_i(t) - e_{\sigma(t_k)}(t)] & if \;\; t \in [t_k, t_k + \tau_D) \wedge |Ce_i(t)| < |Ce_{\sigma(t_k)}(t)|; \\ 0 & otherwise. \end{cases}$$

minimum admissible time between two consecutive faults

- **Corollary:** (Efimov, Cieslak, Henry, 2012)

Let T_{r+1}-$T_r \ge T_D$ for all $r>0$. Then there exist T_D and τ_D such that for any $\psi(0)$ and finite $\|d\|$:

$$|\psi(t)| \le \tilde{\nu} e^{-\tilde{\mu} t/T_D} |\psi(0)| + \tilde{\upsilon}\{\|\delta\|_{[0,t)} + \|d\|_{[0,t)}\} + \tilde{\varpi} \max_{1\le i\le N} |\Delta_i|$$

for all t ≥0 and some parameters $\tilde{\nu}_i>0$, $\tilde{\mu}_i>0$, $\tilde{\varpi}_i>0$ and $\tilde{\upsilon}_i>0$.

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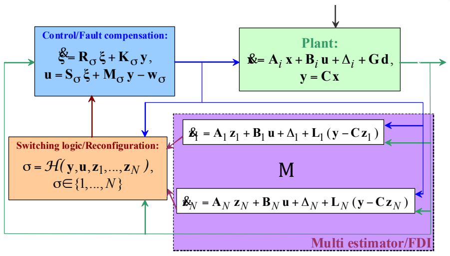
Supervisory FTC with mutual perf. 11/11



- **Stability theorems:** (Efimov, Cieslak, Henry, 2012)

T_D and τ_D are chosen as a criteria for FTC design

⇒ **switch to the adequate controller the more quickly as possible** (minimize τ_D) **keeping the stability**

⇒ **BUT… this approach does not allow to consider FTC + FDI performance**

- **Optimization problem formulation:**

$$(\mathbf{L}_1, \mathbf{R}_1, \mathbf{K}_1, \mathbf{S}_1, \mathbf{M}_1; ...; \mathbf{L}_N, \mathbf{R}_N, \mathbf{K}_N, \mathbf{S}_N, \mathbf{M}_N) = \\ = \arg\min_{\mathbf{L}_1, ..., \mathbf{L}_N; \mathbf{H}_1, ..., \mathbf{H}_N} J_1(\mathbf{L}_1, ..., \mathbf{L}_N; \mathbf{H}_1, ..., \mathbf{H}_N), \ i = \overline{1, N}$$

s.t.

$$\min\{\mathrm{Re}[\lambda(\mathbf{A}_i + \mathbf{L}_i \mathbf{C})]\} < 0$$ ← Stability of the estimators

$$\min\{\mathrm{Re}[\lambda(\mathbf{H}_i)]\} < 0$$ ← Stability of the closed-loop (syst. *k* with cont. *k*)

$$J_1(\mathbf{L}_1, ..., \mathbf{L}_N; \mathbf{H}_1, ..., \mathbf{H}_N) = l_1 \tau_D(\mathbf{L}_1, ..., \mathbf{L}_N; \mathbf{H}_1, ..., \mathbf{H}_N) + \\ + l_2 \max_{1 \le i \le N}\{\| W_i^L(s, \mathbf{L}_i) \| / \| W_i^s(0, \mathbf{L}_i) \|\} + l_3 \max_{1 \le i \le N}\{\| W_i^H(s, \mathbf{H}_i) \|\},$$

maximize the robustness and the fault sensitivity levels of the FDI unit

minimize the dwell-time value

minimize control performances

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Academic illustration 1/4

- **Example:** **F-8 aircraft model (Zhang & Jiang, 2003)**

$$\mathbf{A}_1 = \begin{bmatrix} -3.598 & 0.1968 & -35.18 & 0 \\ -0.0377 & -0.3576 & 5.884 & 0 \\ 0.0688 & -0.9957 & -0.2163 & 0.0733 \\ 0.9947 & 0.1027 & 0 & 0 \end{bmatrix} \quad \mathbf{B}_1 = \begin{bmatrix} 14.65 & 8.79 \\ 0.2179 & 0.1307 \\ -0.0054 & -0.0032 \\ 0 & 0 \end{bmatrix} \quad \mathbf{C} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\Delta_1 = 0$$

The state space vectors : $\mathbf{x} = [p\ r\ \beta\ \phi]^T$ Two ailerons: $\mathbf{u} = [\delta_1\ \delta_2]^T$

Considered faults: stuck actuators $\mathbf{A}_2 = \mathbf{A}_3 = \mathbf{A}_1$

$$\mathbf{B}_2 = \begin{bmatrix} 14.65 & 0 \\ 0.2179 & 0 \\ -0.0054 & 0 \\ 0 & 0 \end{bmatrix} \quad \Delta_2 = \begin{bmatrix} 8.79 \\ 0.1307 \\ -0.0032 \\ 0 \end{bmatrix} \alpha_2 \quad \mathbf{B}_3 = \begin{bmatrix} 0 & 8.79 \\ 0 & 0.1307 \\ 0 & -0.0032 \\ 0 & 0 \end{bmatrix} \quad \Delta_2 = \begin{bmatrix} 8.79 \\ 0.1307 \\ -0.0032 \\ 0 \end{bmatrix} \alpha_2$$

Three distinguished operating modes N=1,2,3,

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Academic illustration 2/4

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- **Example:** **F-8 aircraft model (Zhang & Jiang, 2003)**

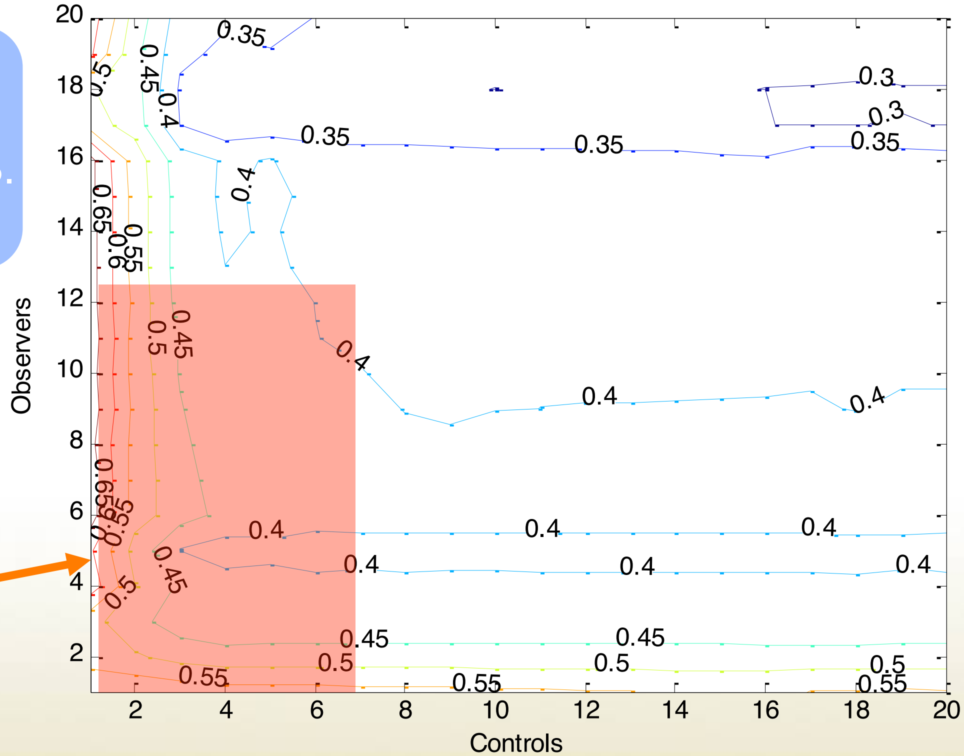
The nonlinear optimization problem is solved using a gridding approach

Solution (optimal) :

$\tau_D = 0.4$ s

$\lambda(\mathbf{A}_i - \mathbf{L}_i\,\mathbf{C}) \approx -8 \qquad i = 1,2,3.$

$\lambda(\mathbf{R}_i) \approx -4$



Admissible H∞ performance zone for control and FDI

- Preliminary
- State-Of-Art
- Supervisory FTC
- **Example**
- Closing words

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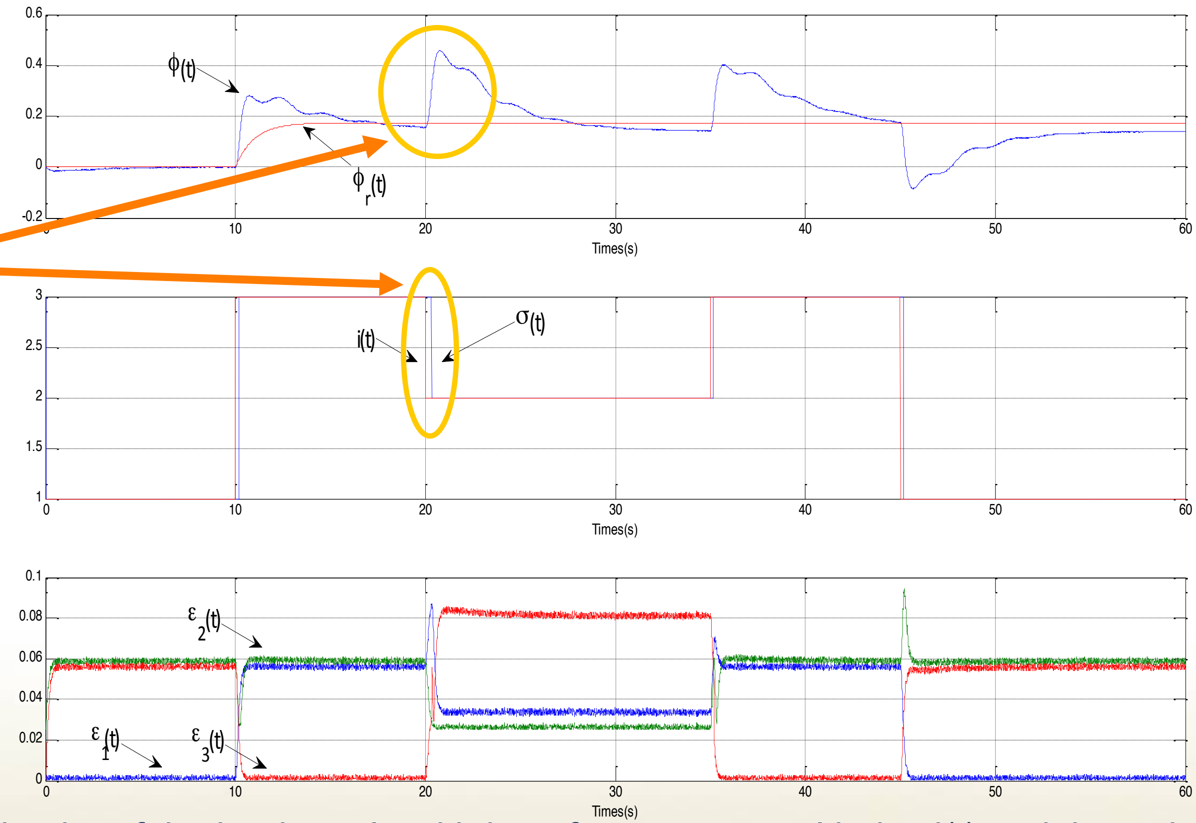
Academic illustration 3/4

- **Example:** F-8 aircraft model (Zhang & Jiang, 2003)

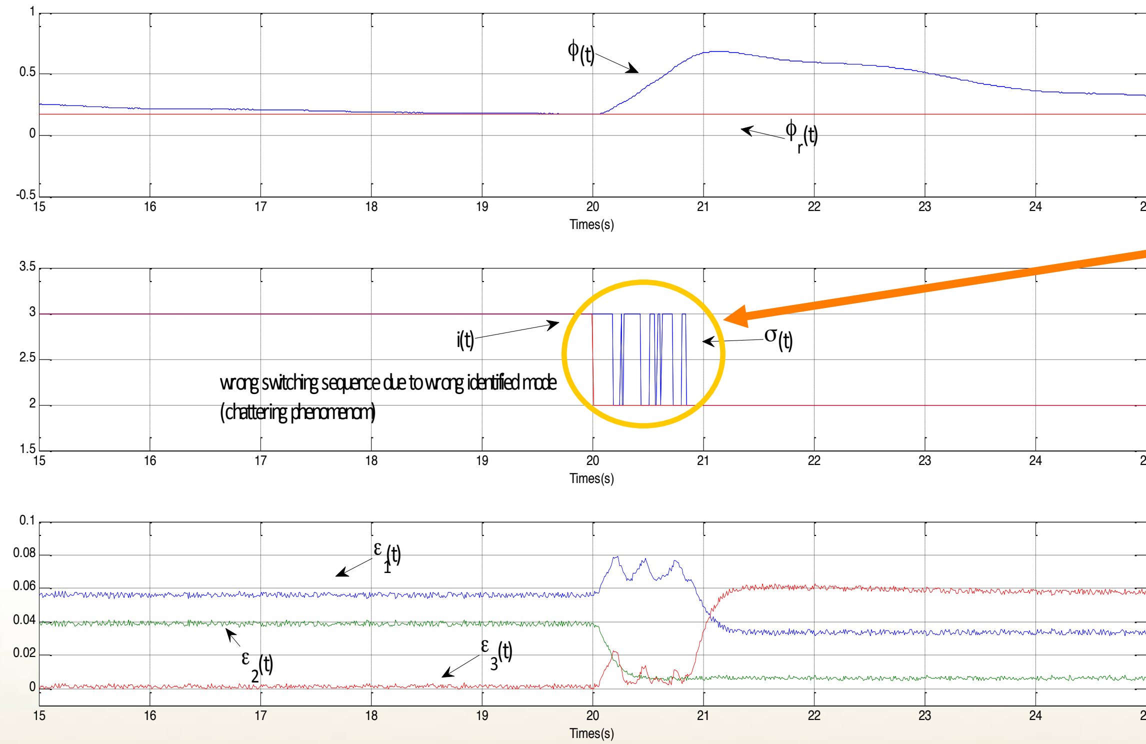
Due to the detection delay



Behavior of the bank angle with its reference, control index i(t) and the switching signal σ(t) and norm of output estimation errors $|Ce_i(t)|$

Academic illustration 4/4

- **Example:** multi-estimator based FDI scheme fails to identify the correct operating mode during some transient…



A chattering phenomenon

BUT

The global stability of the switched system is preserved (thanks to theorems)

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Closing words 1/4

- **Advantages of this type of supervisory FTC approach**
  - Formal stability proofs are established for the overall FTC scheme taking into account all units and bounded disturbances.
  - The method allows to design both the FDI and FTC units taking into account their coupling via an optimization problem.
  - It is proved that the global stability of the control law is preserved even if the FDI scheme fails to identify the correct fault.

- **Enhancement** (already developped in Cieslak, Efimov, Henry, Safeprocess'12)

  ☹ No management of undesirable transient behaviors due to switches

  → Bumpless scheme is added -> Enhancement of dwell-time

  ☹ FT controllers have common state

  → Overall stability is proved with no common state and/or different controller state dimension.

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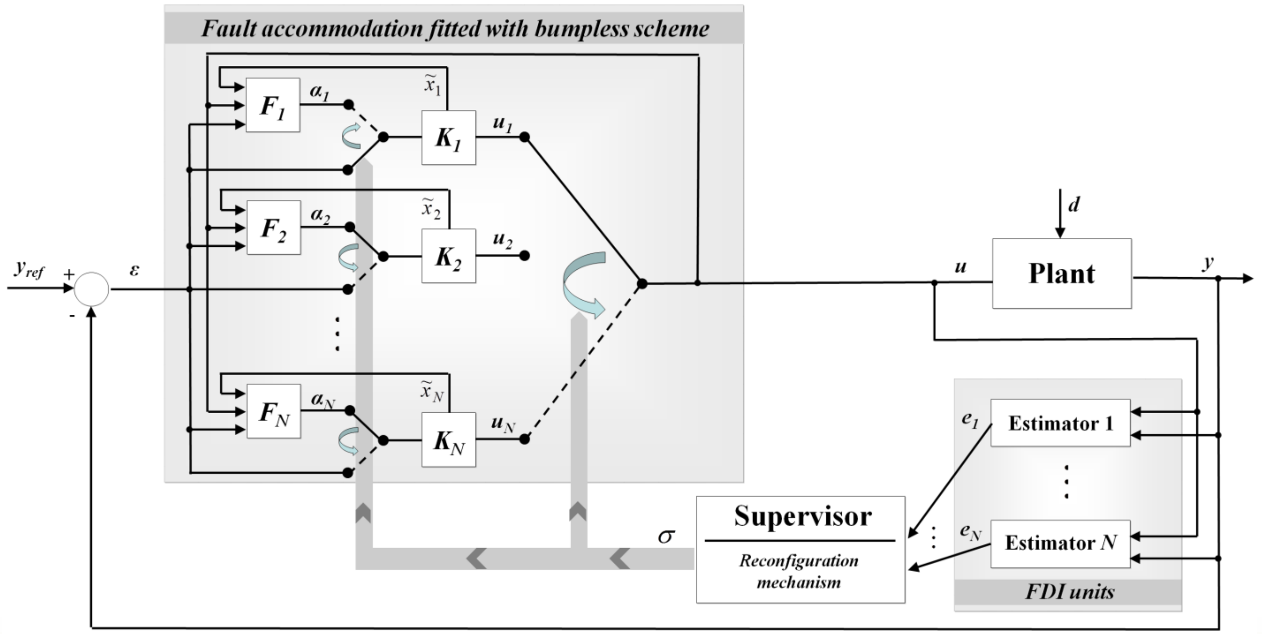
Closing words 2/4

- **Enhancement:** (Cieslak, Efimov, Henry, Safeprocess'12)



where F_i, i=1, ..., N are static gain to be designed such that the following quadratic criterion is minimized:

$$J(u_i,\alpha_i)=\frac{1}{2}\int_0^\infty\left(z_u{}^T W_u z_u + z_e{}^T W_e z_e\right)dt \qquad z_e=\alpha_i-\varepsilon \qquad z_u=u_i-u$$

"Linear quadratic bumpless transfer" Turner M.C. and Walker D.J., *Automatica vol 36 2000.*

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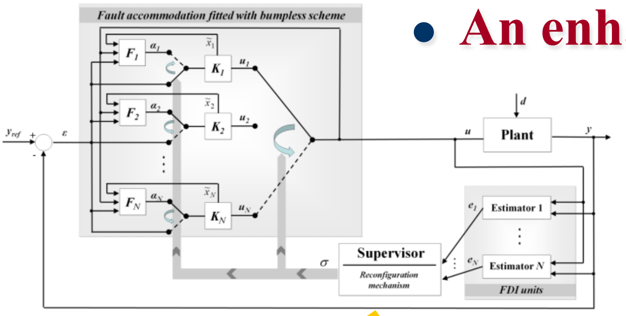
Closing words 3/4



- **An enhancement:** *Using some linear algebra, the supervisory FTC architecture gives the following equations for* $j = 1, \dots N,\ j \neq k$

$$
\begin{cases}
\dot{x} = A_i x + B_i(\tilde{C}_k \tilde{x}_k + \tilde{D}_k y_{ref} - \tilde{D}_k y) + \Delta_i + G_i d \\
\quad = (A_i - L_i C)x + B_i \tilde{C}_k \tilde{x}_k + (L_i - B_i \tilde{D}_k) C z_k + (L_i - B_i \tilde{D}_k) C e_k + B_i \tilde{D}_k y_{ref} + \Delta_i + G_i d - B_i \tilde{D}_k n \\
\dot{\tilde{x}}_k = \tilde{A}_k \tilde{x}_k + \tilde{B}_k y_{ref} - \tilde{B}_k y = \tilde{A}_k \tilde{x}_k - \tilde{B}_k C z_k - \tilde{B}_k C e_k + \tilde{B}_k y_{ref} - \tilde{B}_k n \\
\dot{z}_k = A_k z_k + B_k(\tilde{C}_k \tilde{x}_k + \tilde{D}_k y_{ref} - \tilde{D}_k y) + \Delta_k + L_k(y - C z_k) \\
\quad = B_k \tilde{C}_k \tilde{x}_k + (A_k - B_k \tilde{D}_k C) z_k + (L_k - B_k \tilde{D}_k) C e_k + B_k \tilde{D}_k y_{ref} + \Delta_k + (L_k - B_k \tilde{D}_k) n \\
\dot{z}_j = A_j z_j + B_j(\tilde{C}_k \tilde{x}_k + \tilde{D}_k y_{ref} - \tilde{D}_k y) + \Delta_j + L_j(y - C z_j) \\
\quad = B_j \tilde{C}_k \tilde{x}_k + (L_j - B_j \tilde{D}_k) C z_k + (A_j - L_j C) z_j + (L_j - B_j \tilde{D}_k) C e_k + B_j \tilde{D}_k y_{ref} + \Delta_j + (L_j - B_j \tilde{D}_k) n \\
\dot{\tilde{x}}_j = \tilde{A}_j \tilde{x}_j + \tilde{B}_j F_j \begin{pmatrix} \tilde{x}_j \\ \tilde{C}_k \tilde{x}_k + \tilde{D}_k y_{ref} - \tilde{D}_k y \\ y_{ref} - y \end{pmatrix} \\
\quad = \tilde{B}_j F_{2j} \tilde{C}_k \tilde{x}_k - \tilde{B}_j \mathcal{N} C z_k + (\tilde{A}_j + \tilde{B}_j F_{1j}) \tilde{x}_j - \tilde{B}_j \mathcal{N} C e_k + \tilde{B}_j \mathcal{N} y_{ref} - \tilde{B}_j \mathcal{N} n
\end{cases}
$$

Introducing $\varsigma_k = [z_k^T \ \ \tilde{x}_k^T \ \ x^T \ \ z_1^T \cdots z_N^T \ \ \tilde{x}_1^T \cdots \tilde{x}_N^T]^T$ *such that* $z_1^T \cdots z_N^T$ *and* $\tilde{x}_1^T \cdots \tilde{x}_N^T$ *parts do not contained* z_k^T *and* $\tilde{x}_k^T$ *respectively, we have:*

$$\dot{\varsigma}_k = W_{k,i} \varsigma_k + V_{k,i} C e_k + \iota_{k,i} + \tilde{G}_i d + \bar{G}_i y_{ref} + \bar{\bar{G}}_i n$$

- Preliminary
- State-Of-Art
- Supervisory FTC
- Example
- **Closing words**

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Closing words 4/4

- **And now… the perspectives:**
  - Identification and elaboration of solutions for tackling **static and dynamic** nonlinearities in supervisory control context by means of anti-windup solutions and/or Linear Parameter Varying (LPV) tools.
  - The optimization problem formulation could be enhanced by formulating an optimization problem based on **Linear Matrix Inequalities** (LMI) framework. It offers an appealing context to manage the different specification trade-offs in terms of noise attenuation, sensitivity, tracking,.

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Thank you for your attention

Tolérance aux fautes par une approche superviseur: gestion du couplage FDI-FTC

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