From Robust Control to Adaptive Control

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Outline

- Introduction

- Adaptive control strategies

- Robust control design for adaptive control

- Parameter estimators

- Adaptive control with multiple models

- Experimental results (flexible transmission)

- Concluding remarks

Robust Control

uncertainties → structured *(parameter variations)*

uncertainties → unstructured *(often in high frequencies)*

Performance may be limited (for large plant uncertainties)

Adaptive Control

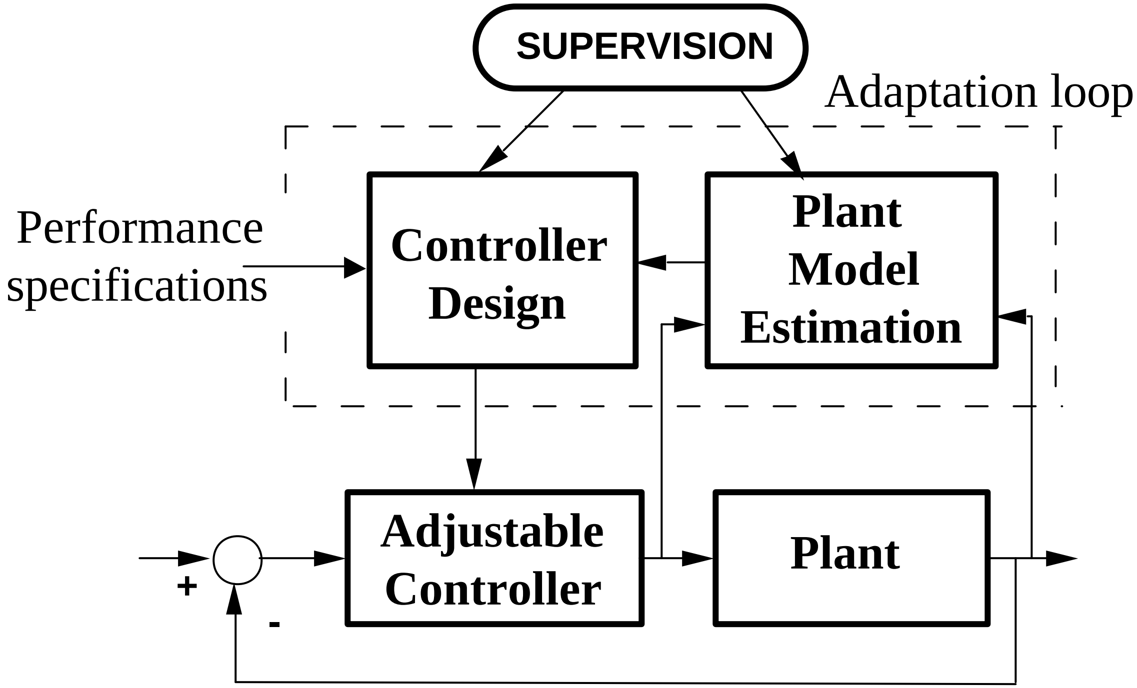
-Well suited for handling parameter variations
- Should work correctly in the presence of « unstructured uncertainties » (parasitics)
- Problems for large and abrupt changes in plant parameters

Robust Control plays an important role in Adaptive Control
(directly or indirectly)

Adaptive Control can improve the performances of a Robust Controller

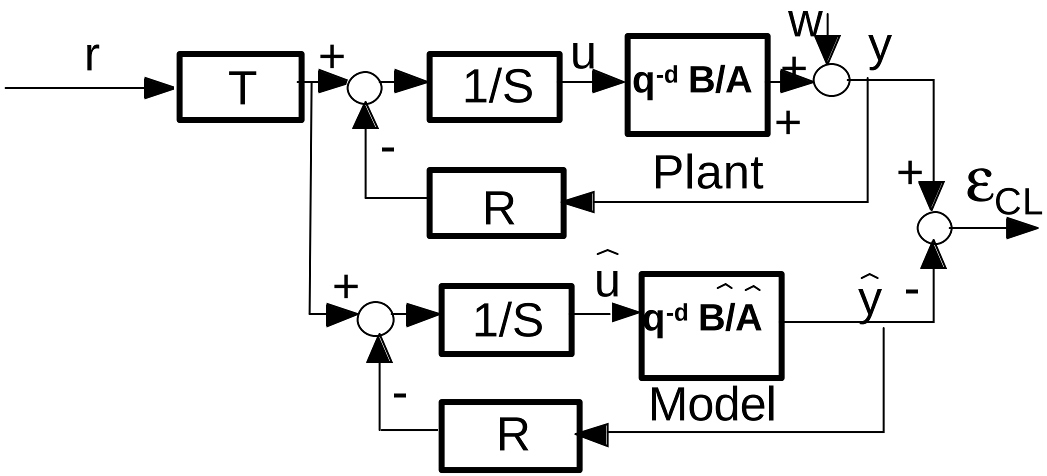
Identification in Closed Loop allows to establish links between Robust Control and Adaptive Control

Adaptive Control – A Basic Scheme



- Indirect adaptive control
- Direct adaptive control *(the controller is directly estimated)*

Iterative Identification in Closed Loop and Controller Re-Design



Step 1 : Identification in Closed Loop

-Keep controller constant

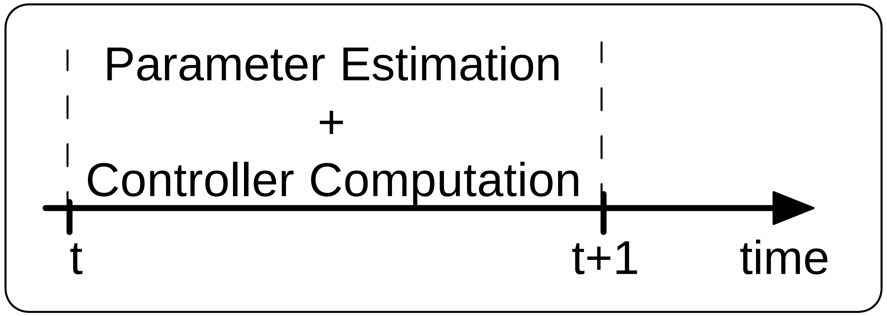
-Identify a new model such that ε_{CL} ↘

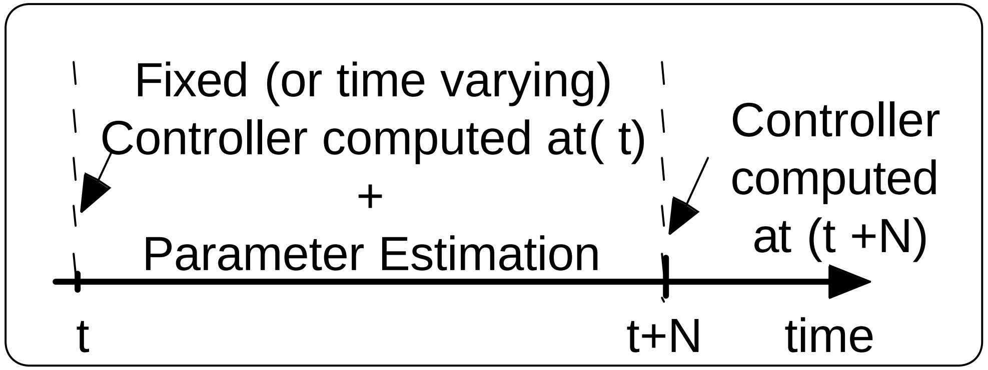
Step 2 : Controller Re – Design

- Compute a new controller such that ε_{CL} ↘

Repeat 1, 2, 1, 2, 1, 2,…

Iterative Identification and Controller Redesign versus (Indirect) Adaptive Control





$N = 1$: Adaptive Control

$N = Small$

Adaptive Control

$N = Large$

Iterative Identification in C.L.
And Controller Re-design

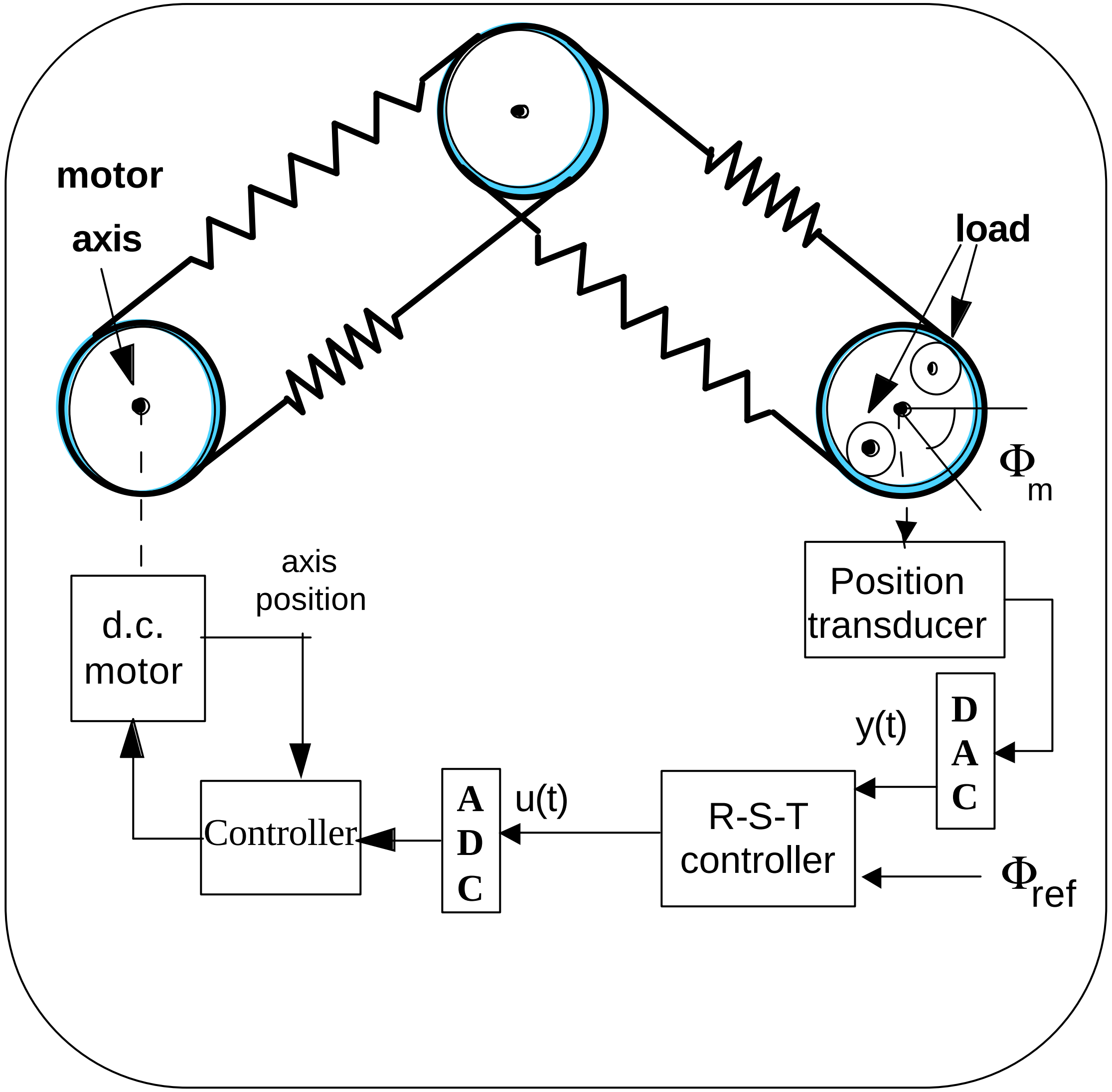
$N \Rightarrow \infty$

Plant Identification in C.L. +
Controller Re-design

The *iterative procedure* introduces a time scale separation between identification / control design

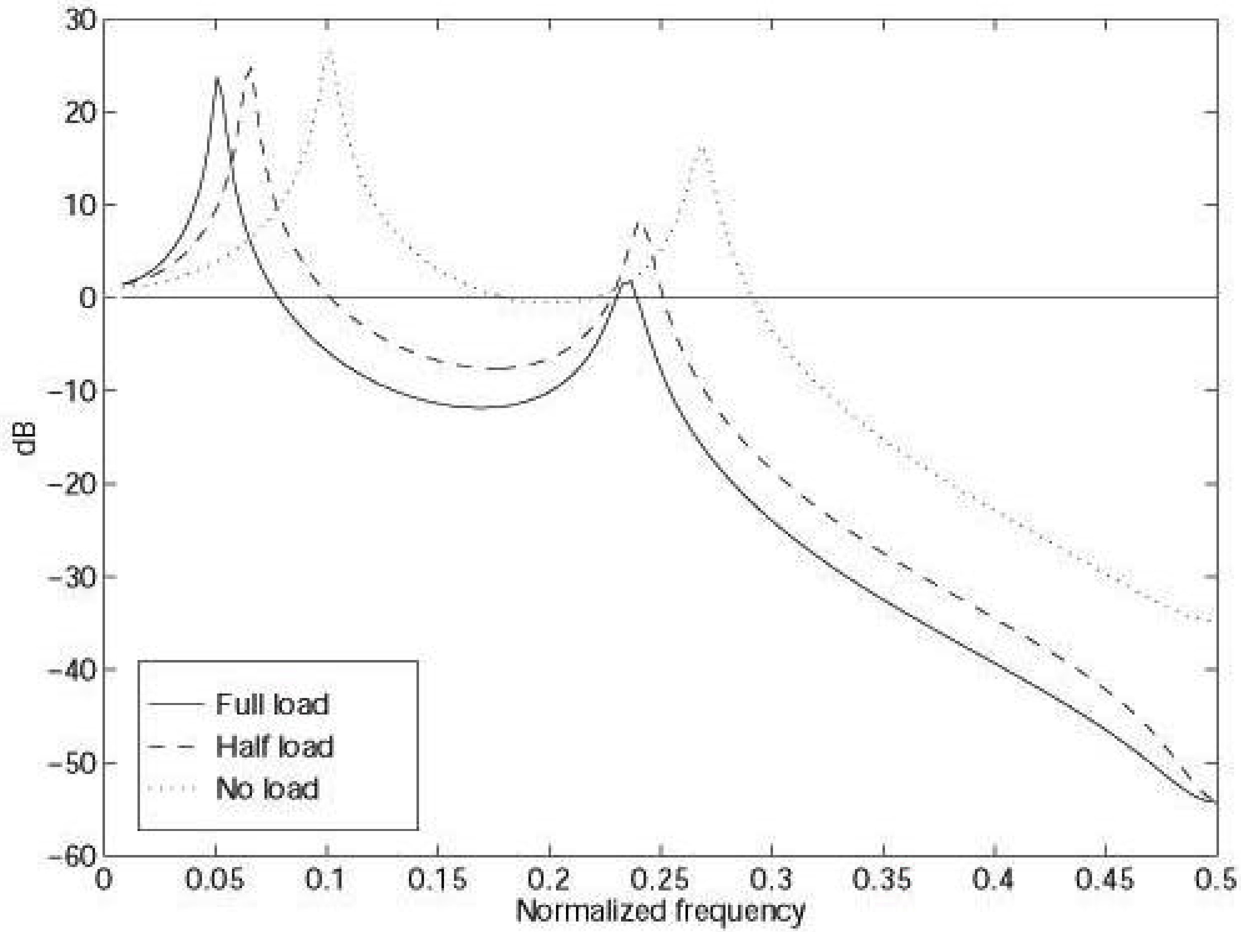
Adaptive Control of a Flexible Transmission

The flexible transmission



Adaptive Control of a Flexible Transmission

Frequency characteristics for various load



Rem.: the main vibration mode varies by 100%

Robust Control Design for Adaptive Control

parameter variations (low frequency) → **Adaptation**

unstructured uncertainities (high frequency) → **Robust Design**

Basic rule : The *input sensitivity function* (S_{up}) should be small in medium and high frequencies

Pole Placement :

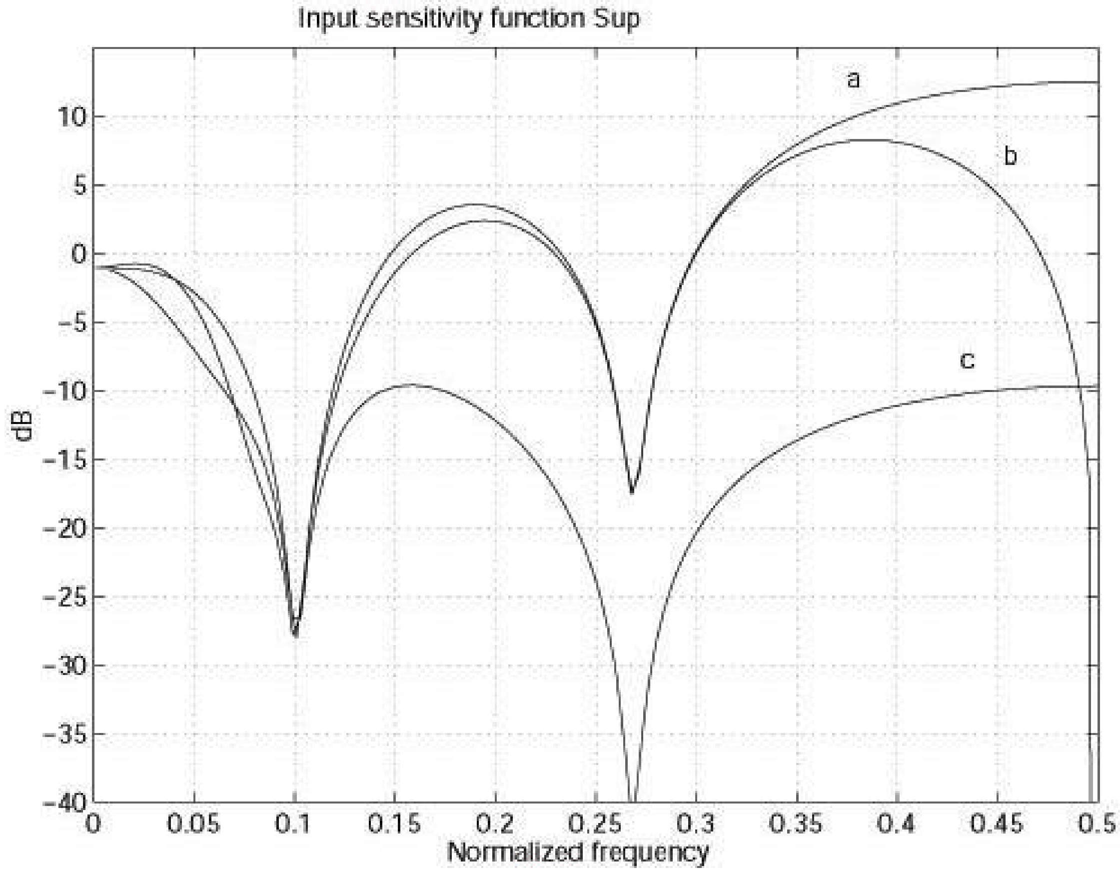
- Opening the loop in high frequncies (at $0.5f_s$)
- Placing auxiliary c.l. poles near the high frequency poles of the plant model

Generalized Predictive Control :

- Appropriate weighting filter on the control term in the criterion

Robust Control Design for Adaptive Control

(Flexible Transmission)



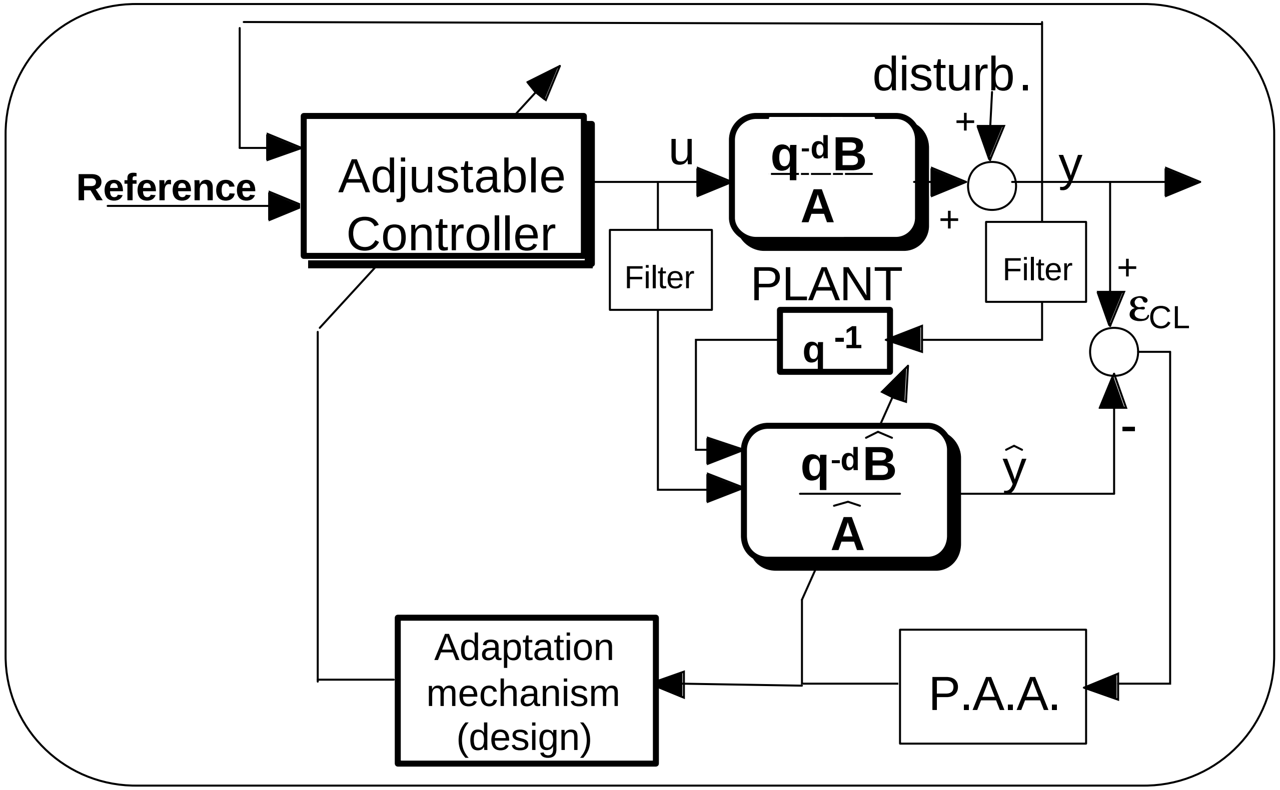
a) Standard pole placement (1 pair dominant poles + h.f. aperiodic poles)

b) Opening the loop at $0.5f_S$ ($H_R = 1 + q^{-1}$)

c) Auxiliary closed loop poles near high frequency plant poles

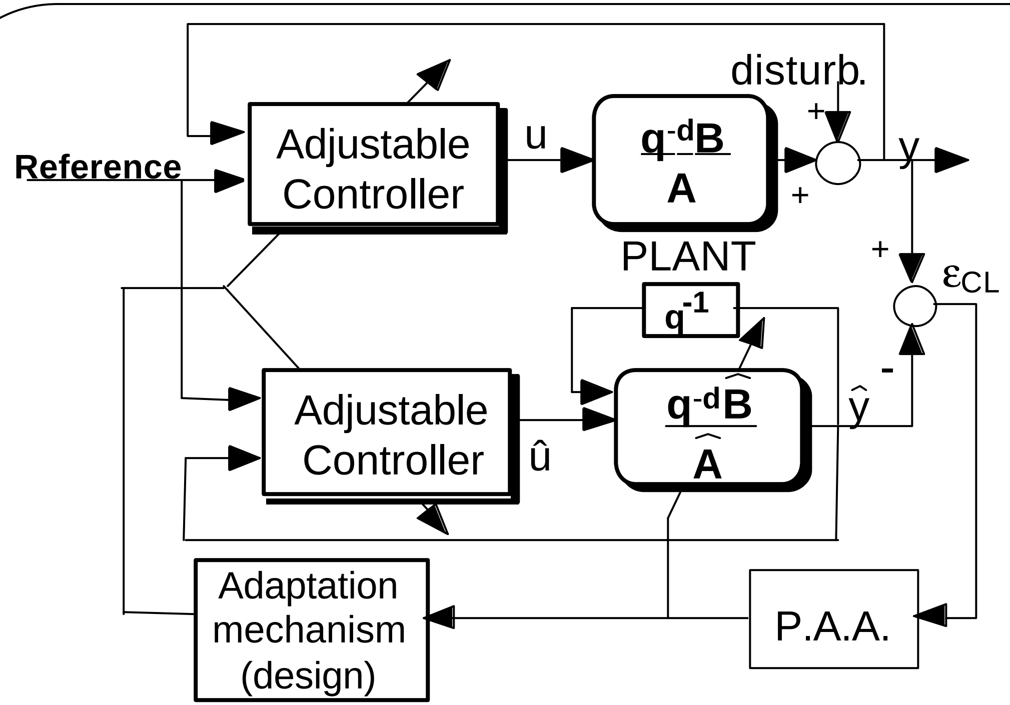
Parameter Estimators for Adaptive Control

Classical Indirect Adaptive Control



- Uses R.L.S. type estimator (equation error)
- Sensitive to output disturbances
- Requires « adaptation freezing » in the absence of persistent excitation
- the thrshhold for « adaptation freezing » is problem dependent

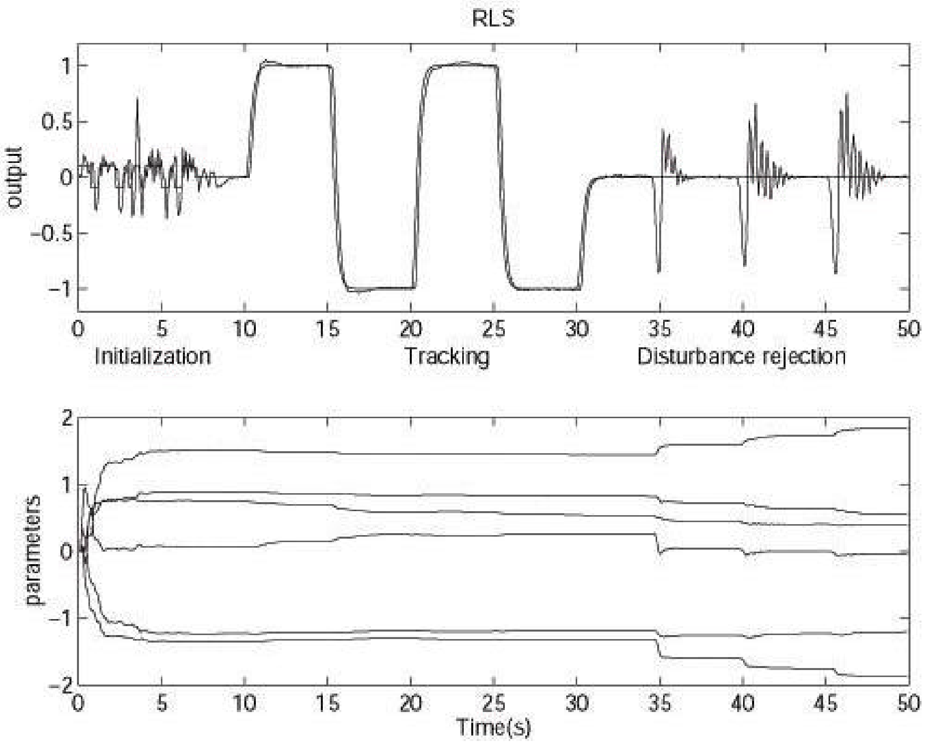
Closed Loop Output Error Parameter Estimator for Adaptive Control



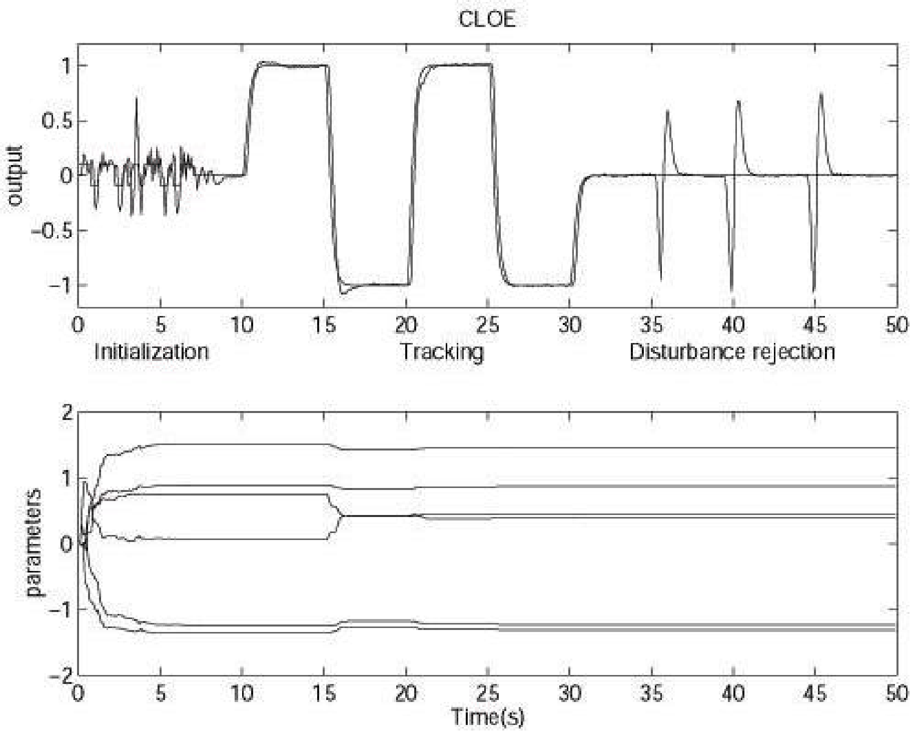
- Insensitive to output disturbances
- Remove the need for « adaptation freezing » in the absence of persistent excitation
- CLOE requires stability of the closed loop
- Well suited for « adaptive control with multiple models »

Adaptive Control – Effect of Disturbances

Classical parameter estimator
(filtered RLS)



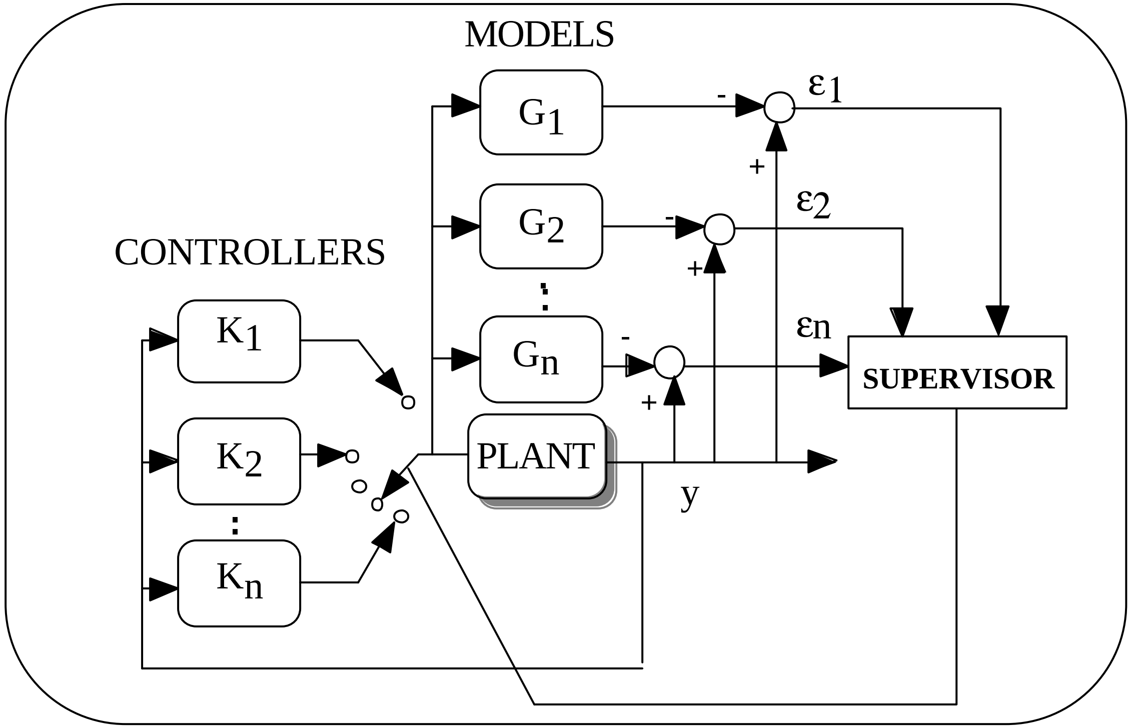
CLOE parameter estimator



Disturbances destabilize the adaptive system when using RLS parameter estimator (in the absence of variable reference signal)

Adaptive Control with Multiple Models

Supervisory Control



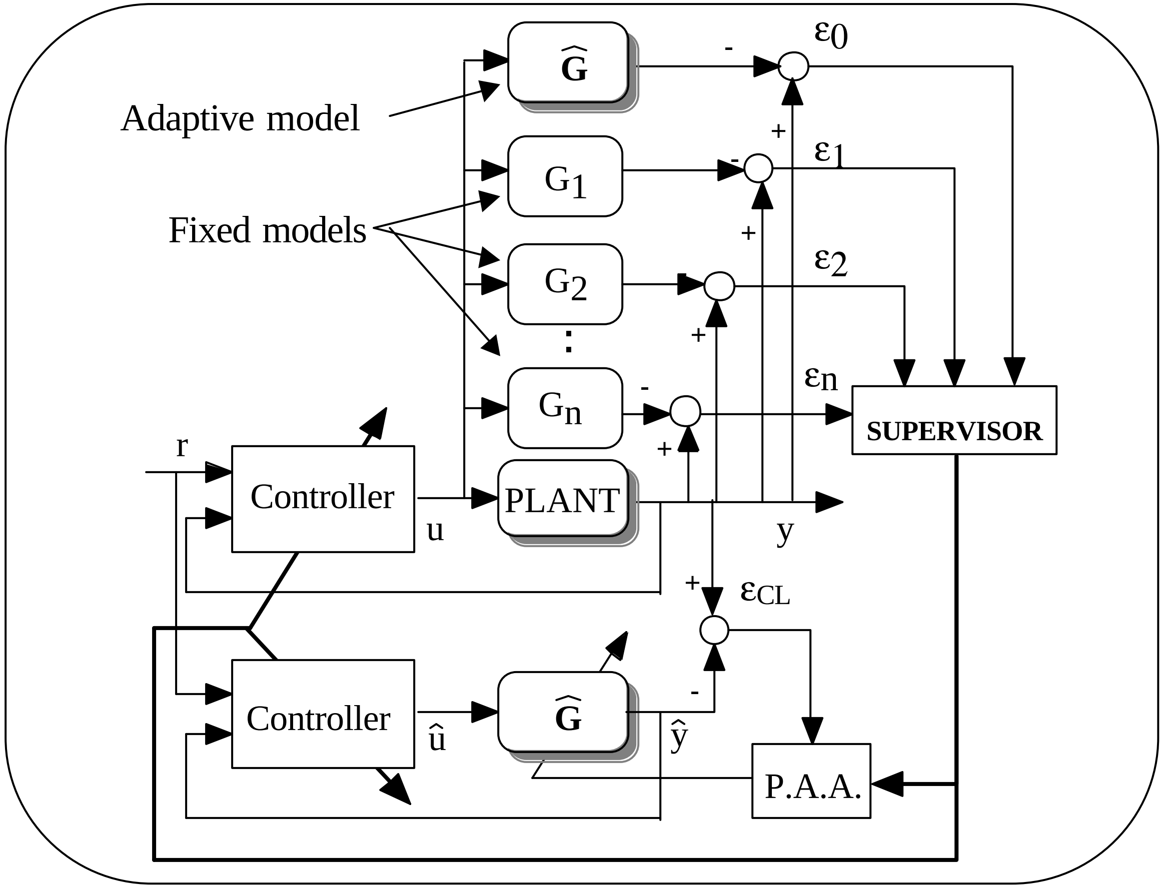
Performance criterion:

$$J_i(t) = a e_i^2(t) + b \sum_{j=0}^{t} e^{-l(t-j)} e_i^2(j); \; a \geq 0, \; b \geq 0, \; i = 1, 2 \ldots n$$

Switching rule: $\min_i J_i(t)$

Rem. : *stability requires the use of hysteresis or time delay in switching*

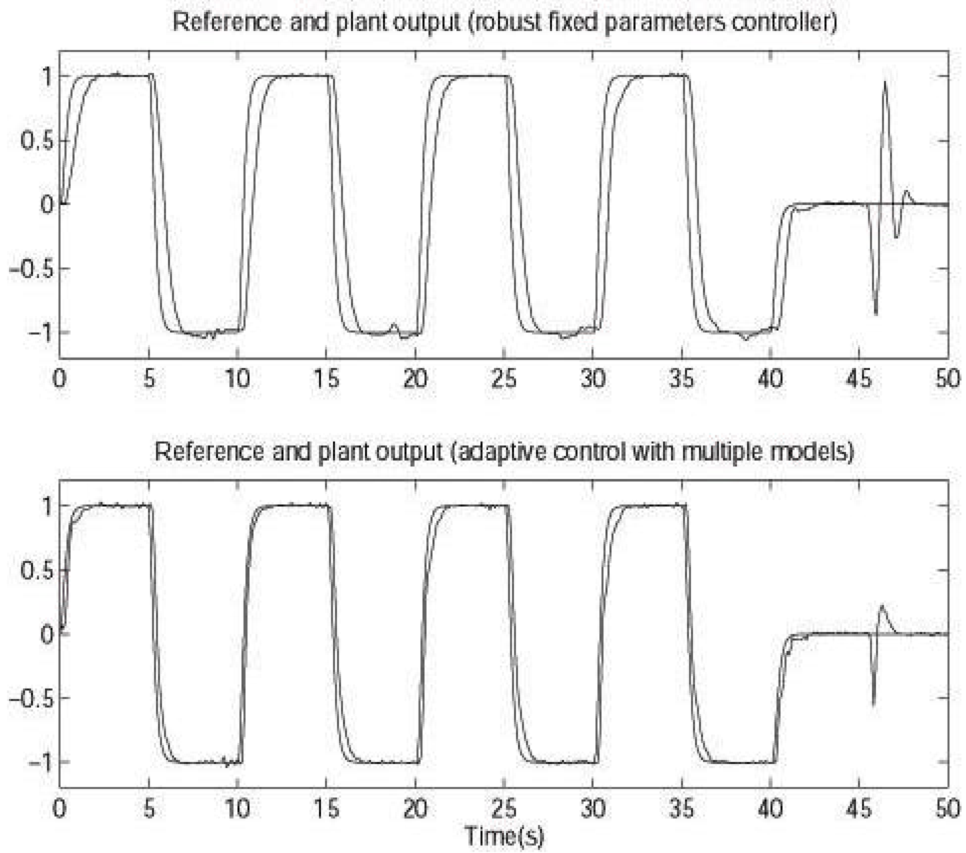
Adaptive Control with Multiple Models



n is small (for the flexible transmission n = 3)

Multiple models : *improvement of the adaptation transients*
CLOE Estimator : *reduction of the false swithchings, performance improvement*

Adaptive Control versus Robust Control

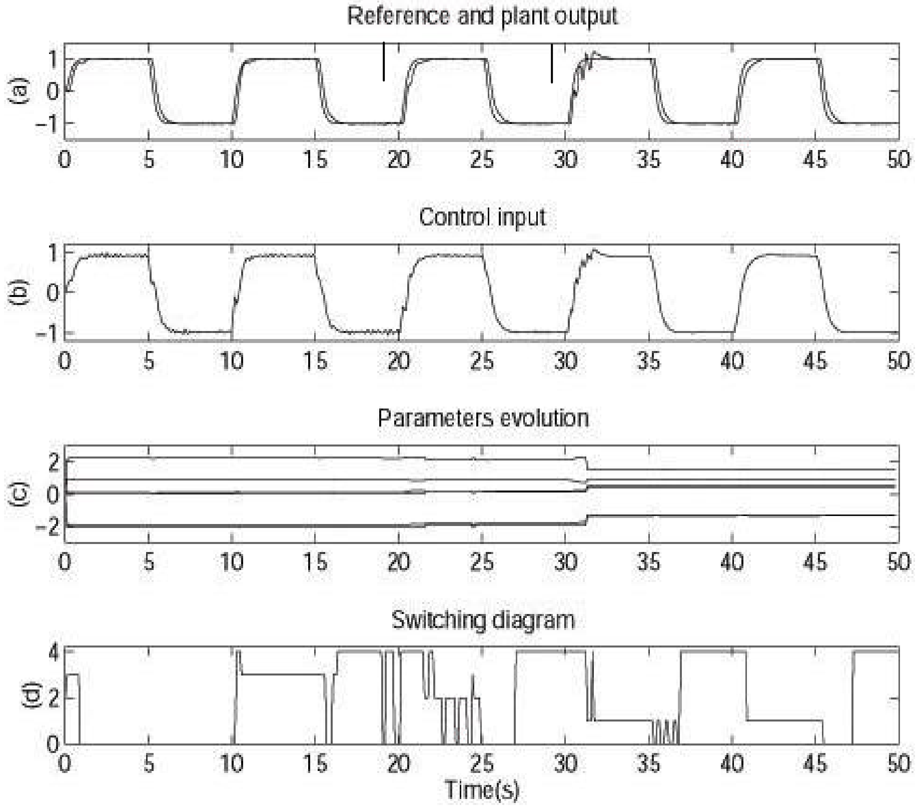


Load variations : 0% → 100% (in several steps)

Rem : The robust controller used is the winner of an international benchmark test for robust control of the flexible transmission (EJC, no.2., 1995)

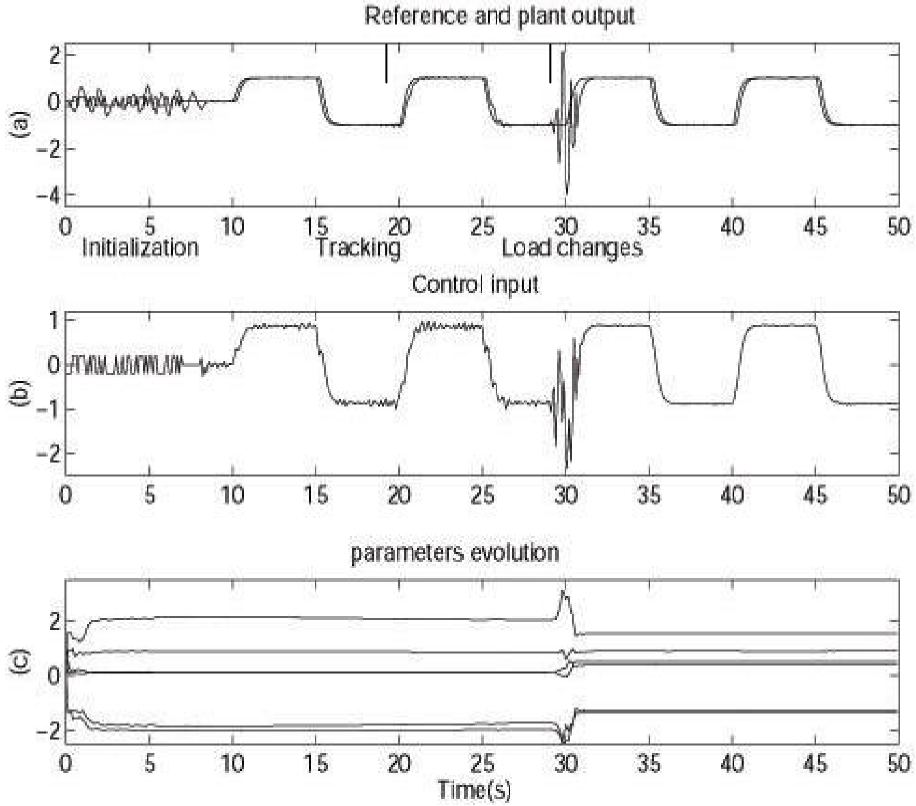
Adaptation Transients

Adaptive Control with Multiple Models



0 = adaptive ; 1= 0% ; 2 = 50% ; 3 = 100%

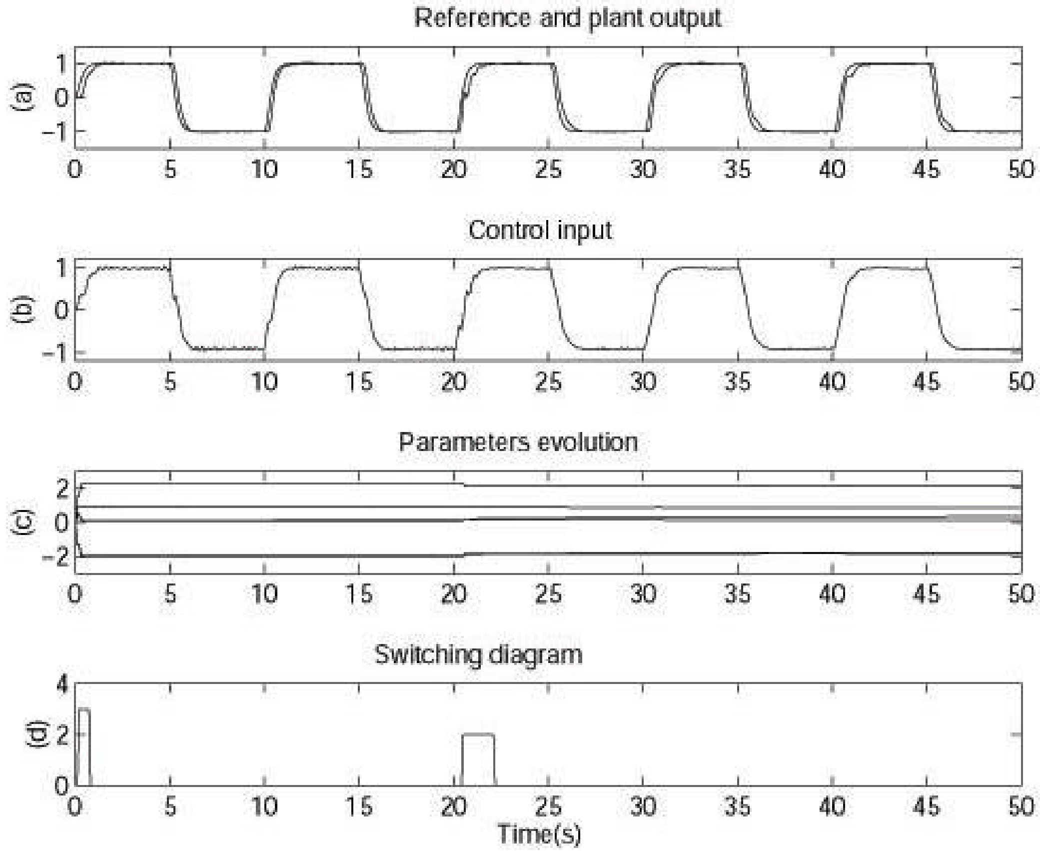
Classical Adaptive Control (simulation)



Load variations : 100% → 0% (in two steps at 19s and 29s)

Adaptive Control with Multiple Models

The « plant models » are not in the « model set »



0 = adaptive ; 1= 0% ; 2 = 50% ; 3 = 100%

Load variations : 75% → 25%

Concluding Remarks

- Identification in closed loop establishes a bridge between robustness and adaptation

- *Iterative identification in closed loop and controller re-design* is a two times scales adaptive control

- Robust linear design in high frequency is needed

- The « multiple models » approach to adaptive control improves significantly the adaptation transients

- There are still important theoretical problems to be solved (ex.: adaptation transients analysis)

References

Morse A.S. (1995) « Control using logic –based switching » in *Trends in Control (A. Isidori, ed.)* Springer Verlag, London, U.K.

Narendra K.S., Balakrishnan (1997) « Adaptive control using multiple models » *IEEE Tr. on Aut. Control*, AC-42, pp. 171-187

Karimi A., Landau I.D.(2000) « Robust adaptive control of a flexible transmission System using multiple models », *IEEE Tr. on Contr.Syst.Technology*.March

Landau I.D., Lozano R., M'Saad M., (1997) : *Adaptive Control*, Springer, London,U.K.

I.D.Landau I.D(1999) « From robust control to adaptive control » *Control Eng.Practice*, vol 7,no10, pp1113-1124