From Robust Control to Adaptive Control

I.D. Landau
Laboratoire d’Automatique de Grenoble, (INPG/CNRS), France

April 2002
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)
- 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 $\varepsilon_{CL}$

**Step 2: Controller Re-Design**
- Compute a new controller such that $\varepsilon_{CL}$

Repeat 1, 2, 1, 2, 1, 2,…
Iterative Identification and Controller Redesign versus (Indirect) Adaptive Control

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

\[ N = I : \text{Adaptive Control} \]

\[ N = \text{Small} \]
Adaptive Control

\[ N = \text{Large} \]
Iterative Identification in C.L.
And Controller Re-design

\[ N \Rightarrow \infty \]
Plant Identification in C.L. + Controller Re-design
Adaptive Control of a Flexible Transmission

The flexible transmission

I.D. Landau: From Robust Control to Adaptive Control
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 uncertainties (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 frequencies (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)

Input sensitivity function $\text{Sup}$

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 threshold 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:

\[ J_i(t) = \alpha \varepsilon_i^2(t) + \beta \sum_{j=0}^{t} e^{-\lambda(t-j)} \varepsilon_i^2(j); \alpha \geq 0, \beta \geq 0, i = 1, 2 \ldots n \]

Switching rule: \[ \min_i J_i(t) \]

Rem.: stability requires the use of hysteresis or time delay in switching
n is small (for the flexible transmission n = 3)

Multiple models: *improvement of the adaptation transients*
CLOE Estimator: *reduction of the false switchings, 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)

I.D.Landau : From Robust Control to Adaptive Control
Adaptation Transients

Adaptive Control with Multiple Models

Classical Adaptive Control (simulation)

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

Load variations : 100% $\rightarrow$ 0% (in two steps at 19s and 29s)
Adaptive Control with Multiple Models

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

\[ \begin{align*}
\text{Load variations: } & 75\% \rightarrow 25\%
\end{align*} \]

\[ \begin{align*}
0 &= \text{adaptive} ; & 1 &= 0\% ; & 2 &= 50\% ; & 3 &= 100\%
\end{align*} \]
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)


