Advances in Output Feedback Adaptive and Variable Structure Control of Uncertain Systems

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Brazil

- Population: 180 Millon people
- Resources: biodiversity (Amazon), petroleum, minerals, food, biofuel, etc.

Other Resources

Federal University of Rio de Janeiro - COPPE

- Federal University of Rio de Janeiro
  - First University of Brazil (founded in 1792)
  - 33.000 undergraduate students
  - 10.000 graduate students
- Graduate School in Engineering: COPPE
  - 13 departments
  - 5 departments are top in Brazil
  - The Department of Electrical Engineering has 40 professors
    - Most professors are granted with research fellowships of the Brazilian Research Council
    - 2 Members of the Brazilian Academy of Sciences
    - 3 IEEE Fellows

GSCAR-Group for simulation and Control in Automation and Robotics

- The GSCAR created in 1991
- Develops theoretical and applied research in the areas of Industrial Processes and Robotics
- Actively interacts with other national and foreign universities and research centers
- Underwater robotics has been one of the major activities, motivated and supported by Petrobras (Brazilian Oil Company).
- An original, passive arm based, ROV dynamic positioning system was designed, constructed and tested at sea.
- The developed control schemes are being applied in experimental tests with real manipulators and mobile robots.

GSCAR Research Topics

- **Advanced Control Systems** Develops control methods with high performance and robustness for uncertain dynamic systems. The main techniques under investigation are: Linear and Nonlinear Robust/Adaptive Control, Sliding Mode Control, Intelligent Control.
- **Underwater Robotics**
- **Industrial Robotics**

  Several adaptive and robust control strategies for industrial robotic manipulators.
  Recent interests are in the areas of visual servoing robot control strategies, hybrid force/position robot control.

GSCAR Research Topics

- Industrial Process Control
  - Adaptive and auto-tuning techniques has been developed for industrial PID digital controllers interacting with the Industry.
  - Recent versions auto-tuners were based on genetic algorithms
  - Another current interest of the group is in automated fault detection, diagnosis and reconfiguration systems.
  - Developments in Distributed Digital Control Systems, Industrial Field Netwoks (Fieldbus, Profibus, etc.)
  - Construction of a new Automation and Process Control Laboratory (LEAD) sponsored by Petrobras

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Research topics: SDU factorization

- **Problem:** Generalization of $sign(\underbrace{K_p}_{Matrix!})$ for MIMO MRAC.

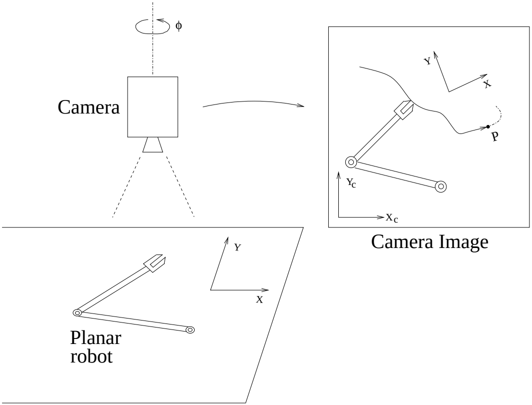
- **Solution:** factorization $K_p = S\,D\,U$

S = symmetric positive definite
D = diagonal
U = unit upper triangular

- $\Longrightarrow$ SDU factorization reduces the problem of designing...

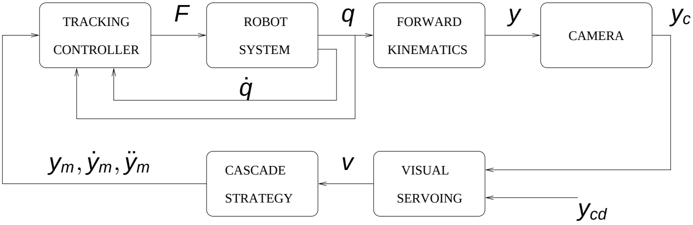
$$
\begin{array}{rcl}
sign(K_p) & \Longrightarrow & sign(D) \\
\text{1 MIMO } (m \times m) \text{ MRAC} & \Longrightarrow & m \text{ SISO MRACs}
\end{array}
$$

- Other results:
  - (IFAC 2008) Improvement of the transient transient
  - (IFAC 2008) Visual servoing with robot/camera uncertain dynamics



ϕ = camera misalignment angle (unknown).

Visual Servoing



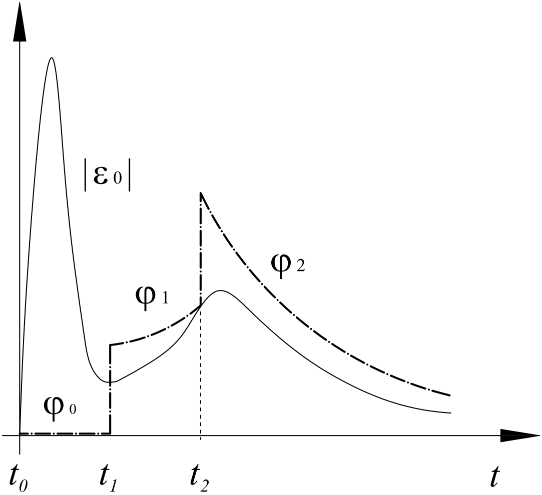
- Design F such that $e = y - y_m \to 0$
- Cascade strategy is defined s.t. $\boxed{\dot{y}_c = K_p\,[v + G(s)\,e]}$
- Thus $y_m, \dot{y}_m, \ddot{y}_m$ do not depend on $\dot{y}_c$
- Design an adaptive visual servoing controller

Monitoring function

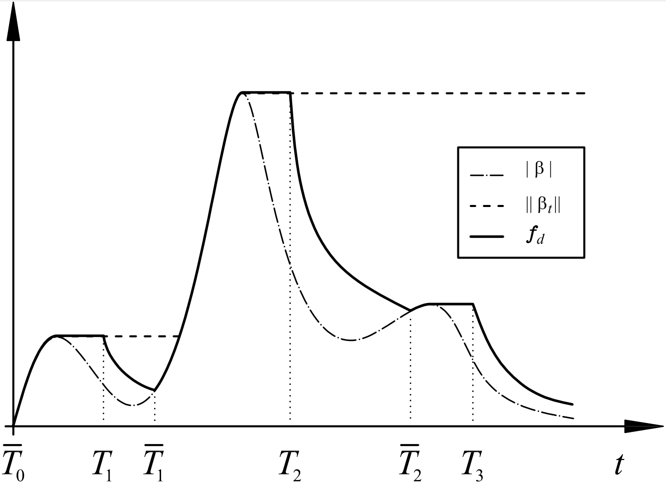
- The problem:

  Given an uncertain plant with unknown control direction, how to make the output track a given desired signal (e.g. generated by a Reference Model).

- The idea: Use Sliding Mode Control and identify the control direction by the use of a monitoring function generated from the stability analysis (by Lin Yan et.al. 2003)

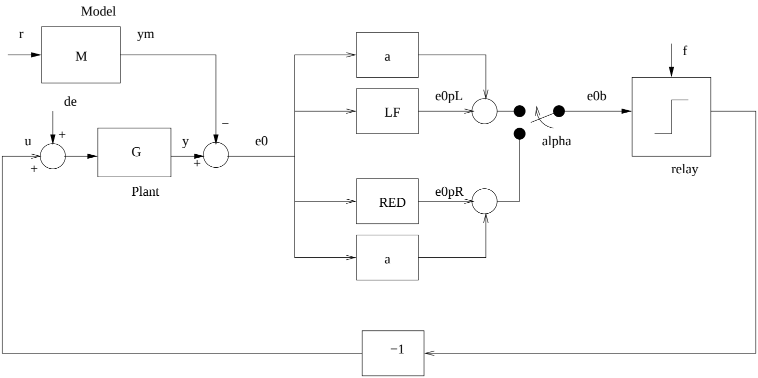


$|\varepsilon_0|$
φ_2
φ_1
φ_0
t_0
t_1
t_2
t



Functions $|\beta|$, $\|\beta_t\|_\infty$ and f_d.

- The method of monitoring function was extended to the case of arbitrary relative degree in the linear case (CDC2006) using a lead filter to compensate the relative degree. Experimental results were shown to validate the method.
- Extended to SISO nonlinear systems (VSS2006, IJACSP2007) and arbitrary relative degree and preliminarily extended to MIMO systems (ACC2007)



(a) cyclic (b) undirected (c) mixed

Global Exact Tracking

- The problem: How to make GLOBAL EXACT output feedback tracking of linear and nonlinear uncertain systems (ACC2004).
- The idea:

  use a switched lead filter consisting of two modes: A conventional linear lead filter and one using EXACT differentiation (locally) based on 2^{nd} order sliding mode. (see above figures).
- Note that usually only practical tracking is achieved (within a small residual error).
- The method was also generalized to a class of nonlinear systems.

New Topics

1. **CNPq Project:**

   Nanopositioning with Piezoelectric Actuators in the presence of uncertainties and nonlinearities

2. **VSS 2008:**

   Global output feedback tracking of Euler-Lagrange Systems (robots, ships, satellites, etc.)

3. **IFAC 2008:**

   Formation control of multiagent systems using adaptive control

Gazi potential function - Possibility of local minima

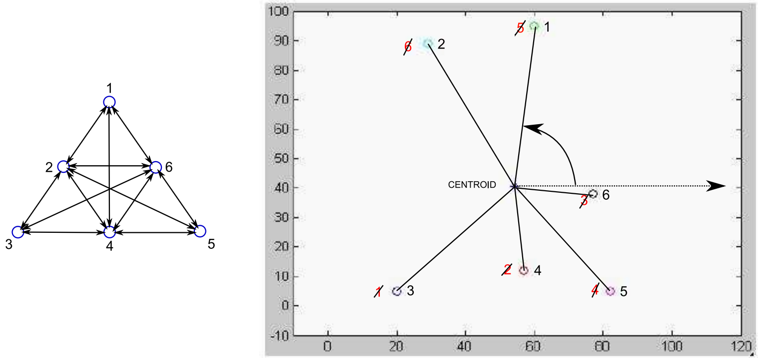


Figure: Initial position reordering

Gazi Potential Function - Initial Reordering

Obstacle avoidance and different formations

Quadratic potential function

- Possibility of collisions

Quadratic potential function

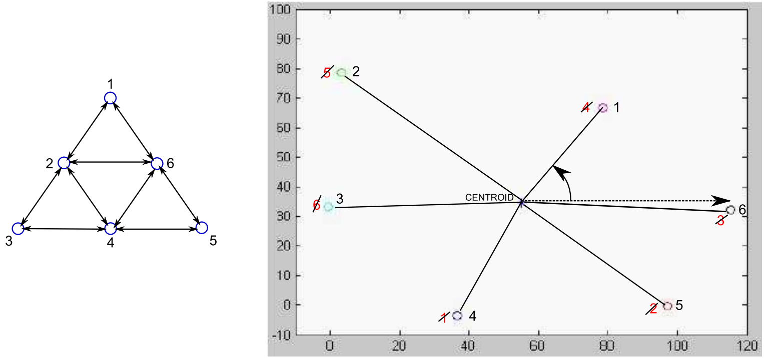


Figure: Initial reordering and reconfiguration of information topology

Quadratic potential function

- Initial reordering and reconfiguration of information topology

Formation control - Trajectory tracking

- One moving virtual leader is added