ICRA16 Workshop on

Application of the theoretical background in Parallel Robotics to other research areas

Advanced control of parallel robots and its extension to other research fields
The concept of "Hidden Robot"

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  - Illustrations

- **Part II The concept of Hidden Robot** *S. Briot*
  - *Concept of Hidden Robot*
  - *Controllability analysis*
  - *Extension of the concept*
  - *Conclusion*

Part I Vision Based Control

- Introduction
- Vision Based Control
- Application to Parallel Robot
- Illustrations

Motivations:

Use exteroceptive sensors which allow to measure directly in task space

Explore the potentialities of vision sensor (but not only)

Try to answer some questions:

- What is the real state for a complex system ?
- What is the real state for a parallel robot?
- Is it possible to control by vision only in kinematics/dynamics?
- Is it accurate enough?
- Does it work in a big workspace?

Can we define a generic and integrated formalism for modelling/Identification and control (MICMAC) for complex machines (Parallel robots)? In kinematics ? … Dynamics ?

Research done at LASMEA *2000-2011* (Pascal Institute in Clermont-Fd)

Nicolas Andreff

PhD

Pierre Renaud

Tej Dallej

Erol Özgür

Ludovic Magerand

Arnaud Marchadier
Master

Flavien Paccot

Redwan Dahmouche

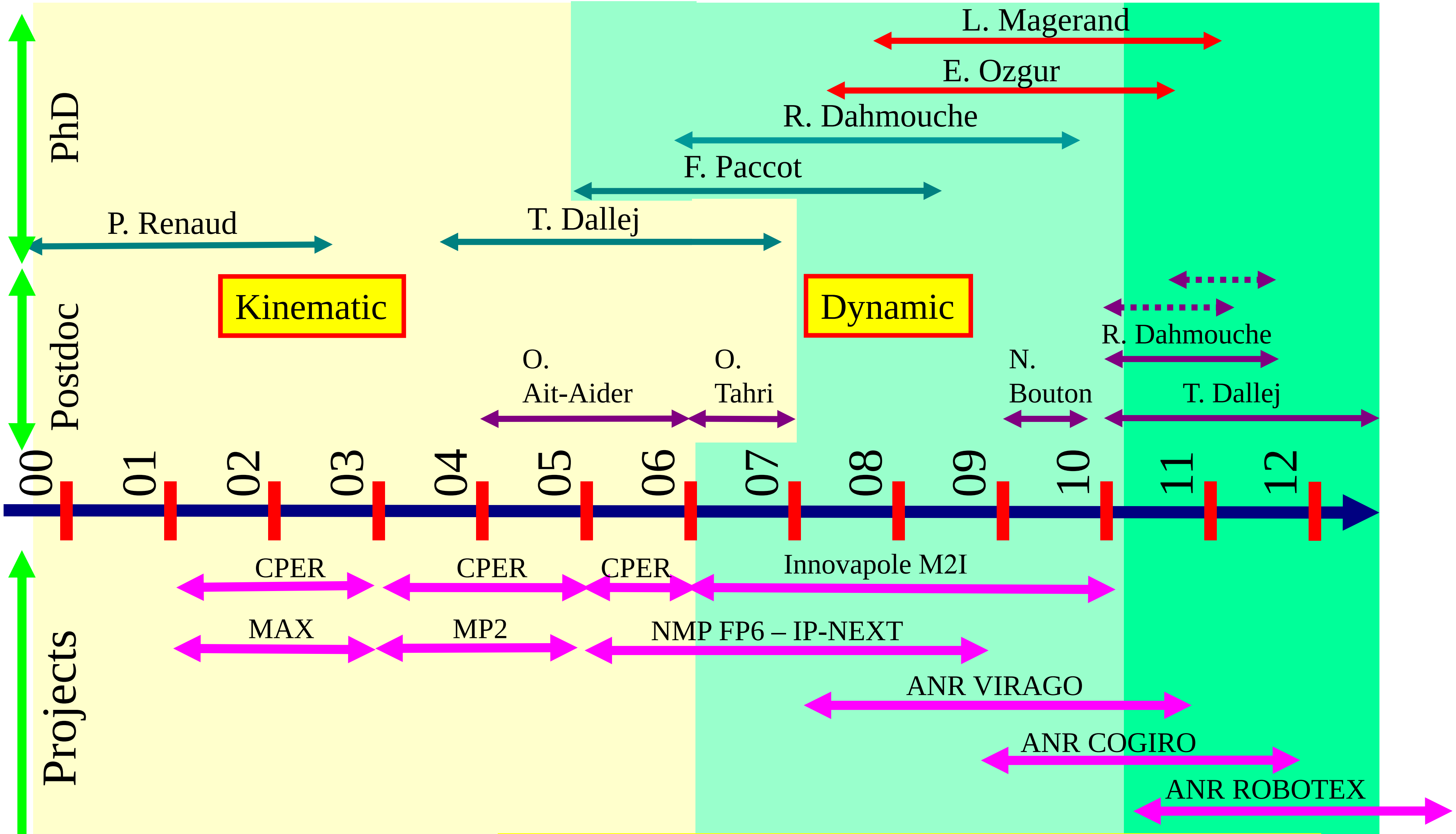
PostDoc

Omar Ait-Aider

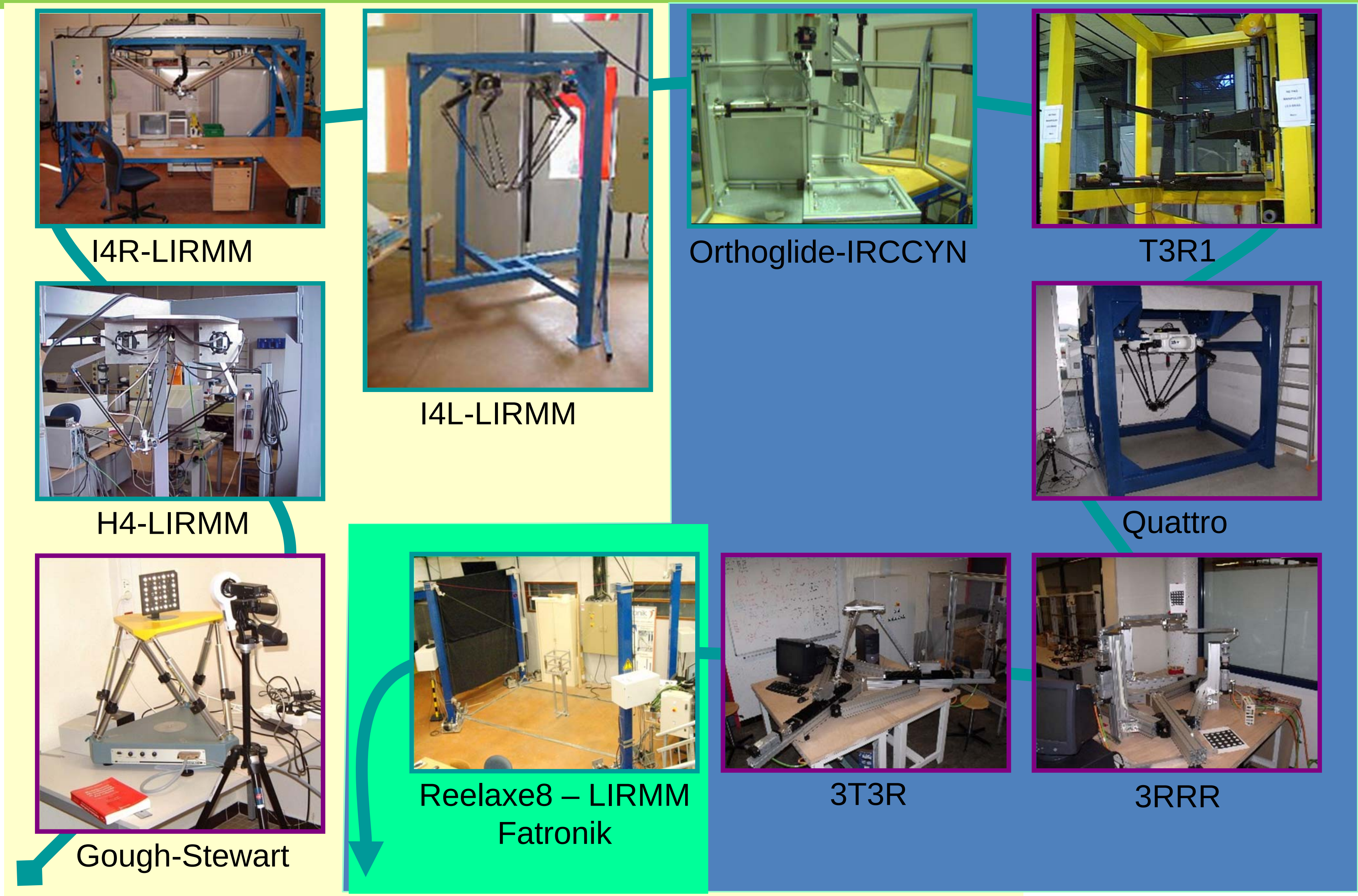
Omar Tahri

Nicolas Bouton

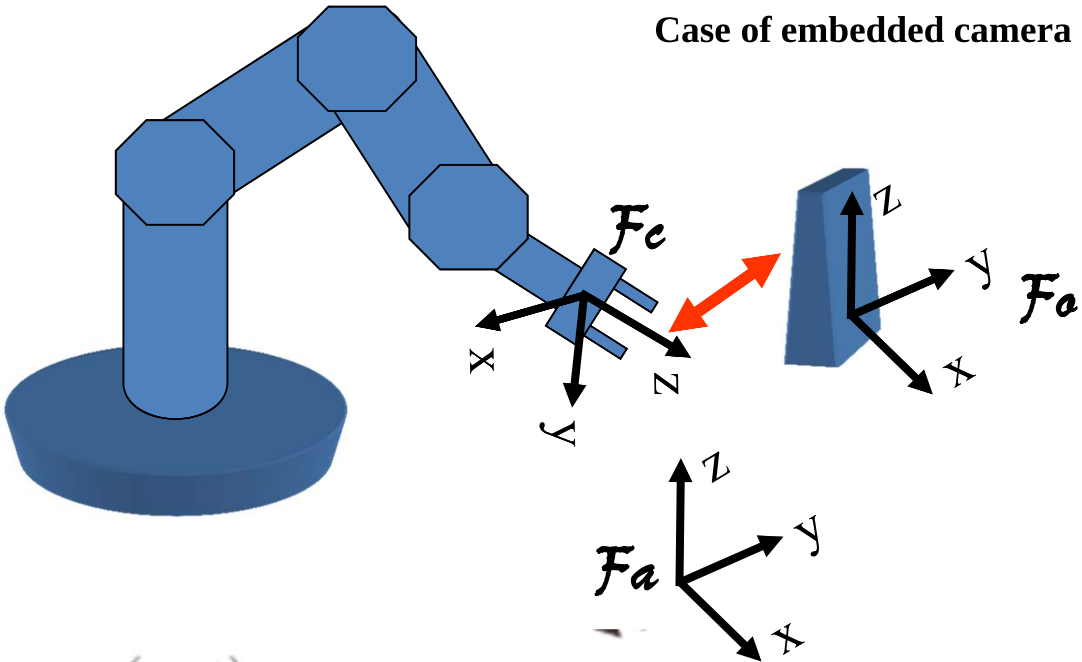
Tej Dallej

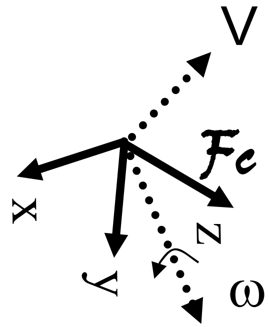


Total: 10 years, 6 PhD, 5 (+2) post-doc, 10+ projects


I4R-LIRMM
I4L-LIRMM
Orthoglide-IRCCYN
T3R1
H4-LIRMM
Quattro
Gough-Stewart
Reelaxe8 – LIRMM
Fatronik
3T3R
3RRR

Case of embedded camera





x : 3D pose

$$\mathbf{s} = \mathbf{s}(\mathbf{x}, t)$$

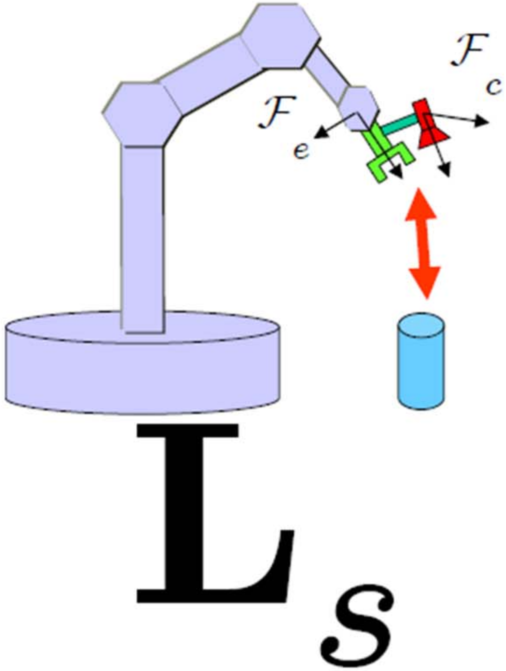
Interaction matrix

If (fixed object) $\frac{\partial \mathbf{s}}{\partial t} = 0$

$$\dot{\mathbf{s}} = \frac{\partial \mathbf{s}}{\partial \mathbf{x}}\frac{d\mathbf{x}}{dt} + \frac{\partial \mathbf{s}}{\partial t} \Rightarrow \dot{\mathbf{s}} = \mathbf{L}_s \mathbf{v} + \frac{\partial \mathbf{s}}{\partial t}$$

$$\dot{\mathbf{s}} = \mathbf{L}_s \mathbf{v}$$

Embedded camera
(Eye in hand)



- $\mathcal{F}_c$ Camera frame
- $\mathcal{F}_e$ End effector frame

$\dot{\mathbf{s}} = \mathbf{L}_s \mathbf{v}$ ← **Camera intrinsic parameters In $\mathcal{F}_c$**

$\dot{\mathbf{x}} = \mathbf{L}_{\mathbf{x}} \mathbf{v}_e$

$\mathbf{v} = -\lambda \mathbf{L}_s^{+} (\mathbf{s} - \mathbf{s}^*)$

$\mathbf{v}_e = {}^e\mathbf{V}\, \mathbf{v}$ ← **Camera extrinsic parameters**

$\dot{\mathbf{q}} = \mathbf{J}(\mathbf{q})^{-1}\, \mathbf{L}_{\mathbf{x}}\, \mathbf{v}_e = \mathbf{J}(\mathbf{q})^{-1}\, \mathbf{L}_{\mathbf{x}}\, {}^e\mathbf{V}\, \mathbf{v}$

↑ **Robot jacobian expressed in $\mathcal{F}_e$**

Classical Visual servoing concentrates on modelling the interaction between

- Embedded sensor and environment (case of Eye In Hand)
- Gripper and object (case of Eye to Hand)

S can be a feature of different nature : 3D/2D/Hybrid

which

- characterizes the interaction with the environment (relative situation between the end effector and the environment)
- don’t characterize any the internal state of the robot

$$\dot{\mathbf{s}} = \mathbf{L}_s \mathbf{v}$$

Generally, we define a task error,

$$\mathbf{e} = C(\mathbf{s}(t) - \mathbf{s}^*)$$

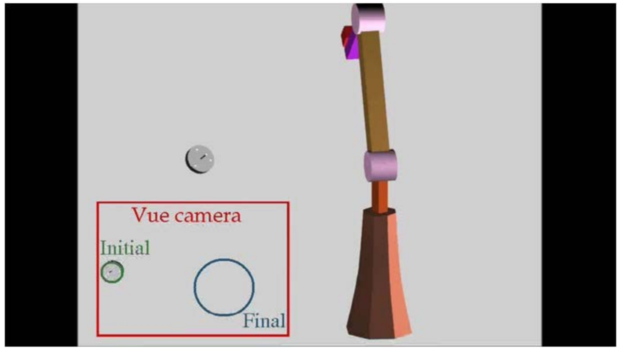
and we impose an exponential decrease of the error which gives a proportional control law

$$\dot{\mathbf{e}} = -\lambda \mathbf{e}$$

$$\mathbf{v} = -\lambda \mathbf{e}$$

$$\mathbf{v} = -\lambda \mathbf{L}_s^+ (\mathbf{s}(t) - \mathbf{s}^*)$$

e must be a diffeomorphism with the state of the system



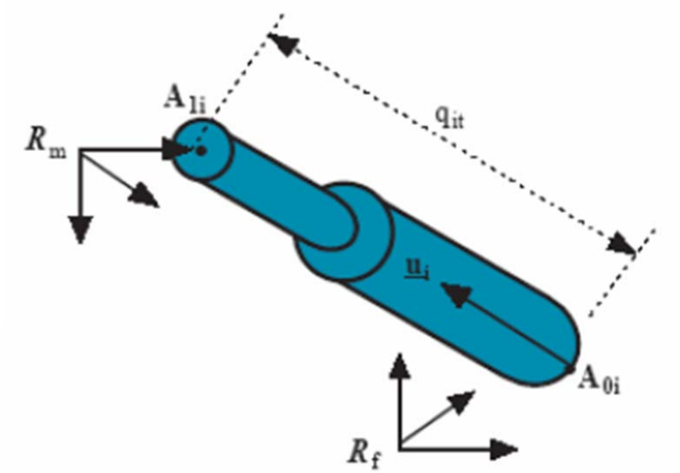
L^+ must be not singular with no degenerated cases

(s-s*) must be not in the kernel of L^+ (case of local minima)

Serial robots and parallel robots

	Serial robots	Parallel robots
Kinematic Modelling	$\mathbf{q} \overset{\mathbf{f}(\mathbf{q})}{\Longrightarrow} \mathbf{X}$, inverse: $\mathbf{g}(\mathbf{q})$	$\mathbf{X} \overset{\mathbf{g}(\mathbf{X})}{\Longrightarrow} \mathbf{q}$, inverse: $\mathbf{f}(\mathbf{X})$
	$\mathbf{q} \Rightarrow \mathbf{X} = \mathbf{f}(\mathbf{q})$	$\mathbf{X} \Rightarrow \mathbf{q} = \mathbf{g}(\mathbf{X})$
	$\mathbf{f}(\mathbf{q}) \Rightarrow \mathbf{g}(\mathbf{q}) = \mathbf{f}^{(-1)}(\mathbf{q})$	$\mathbf{g}(\mathbf{X}) \Rightarrow \mathbf{f}(\mathbf{X}) = \mathbf{g}^{(-1)}(\mathbf{X})$
Jacobian Matrix	$\dot{\mathbf{q}} \overset{\mathbf{J}(\mathbf{q})}{\Longrightarrow} \dot{\mathbf{X}}$, inverse: $\mathbf{J}^{(-1)}(\mathbf{q})$	$\dot{\mathbf{X}} \overset{\mathbf{J}_{inv}(\mathbf{X})}{\Longrightarrow} \dot{\mathbf{q}}$, inverse: $\mathbf{J}_{inv}^{(-1)}(\mathbf{X})$
	$\dot{\mathbf{X}} = \mathbf{J}(\mathbf{q})\dot{\mathbf{q}}$	$\dot{\mathbf{q}} = \mathbf{J}_{inv}(\mathbf{X})\dot{\mathbf{X}}$
	$\mathbf{J}(\mathbf{q}) \Rightarrow \mathbf{J}^{(-1)}(\mathbf{q})$	$\mathbf{J}_{inv}(\mathbf{X}) \Rightarrow \mathbf{J}_{inv}^{(-1)}(\mathbf{X})$

Kinenamic Vision Based control using leg observation



$$\dot{q} = {}^m D_m^{inv} \cdot {}^m \tau_m \qquad {}^m D_m^{inv} = \begin{pmatrix} {}^m\underline{u}_1^T & {}^m A_{01} \times {}^m \underline{u}_1{}^T \\ {}^m\underline{u}_2^T & {}^m A_{02} \times {}^m \underline{u}_2{}^T \\ \vdots & \vdots \\ {}^m\underline{u}_6^T & {}^m A_{06} \times {}^m \underline{u}_6{}^T \end{pmatrix}$$

$${}^m\dot{\underline{u}}_i = M_i^T \, {}^m\tau_m$$

$$M_i^T = -\frac{1}{q_i}\left(I_3 - {}^m\underline{u}_i {}^m\underline{u}_i^T\right)\left[I_3 \quad -\left[{}^m A_{0i}\right]_\times\right]$$

$\mathbf{M}_i^T$ is obviously of rank 2

$$\begin{aligned} e_i &= {}^m\underline{u}_i \times {}^m\underline{u}_{di} \\ &= -{}^m\underline{u}_{di} \times {}^m\underline{u}_i \\ &= \left[{}^m\underline{u}_{di}\right]_\times^m \underline{u}_i \end{aligned}$$

$$\begin{aligned} \dot{e}_i &= -\left[{}^m\underline{u}_{di}\right]_\times \cdot {}^m\dot{\underline{u}}_i \\ &= -\left[{}^m\underline{u}_{di}\right]_\times M_i^T \, {}^m\tau_m \end{aligned}$$

$$E = (\mathbf{e}_1^T, \ldots, \mathbf{e}_6^T)^T$$

$$N_i^T = -\left[{}^m\underline{u}_{di}\right]_\times M_i^T \text{ and } N^T = (N_1, \ldots, N_6)^T$$

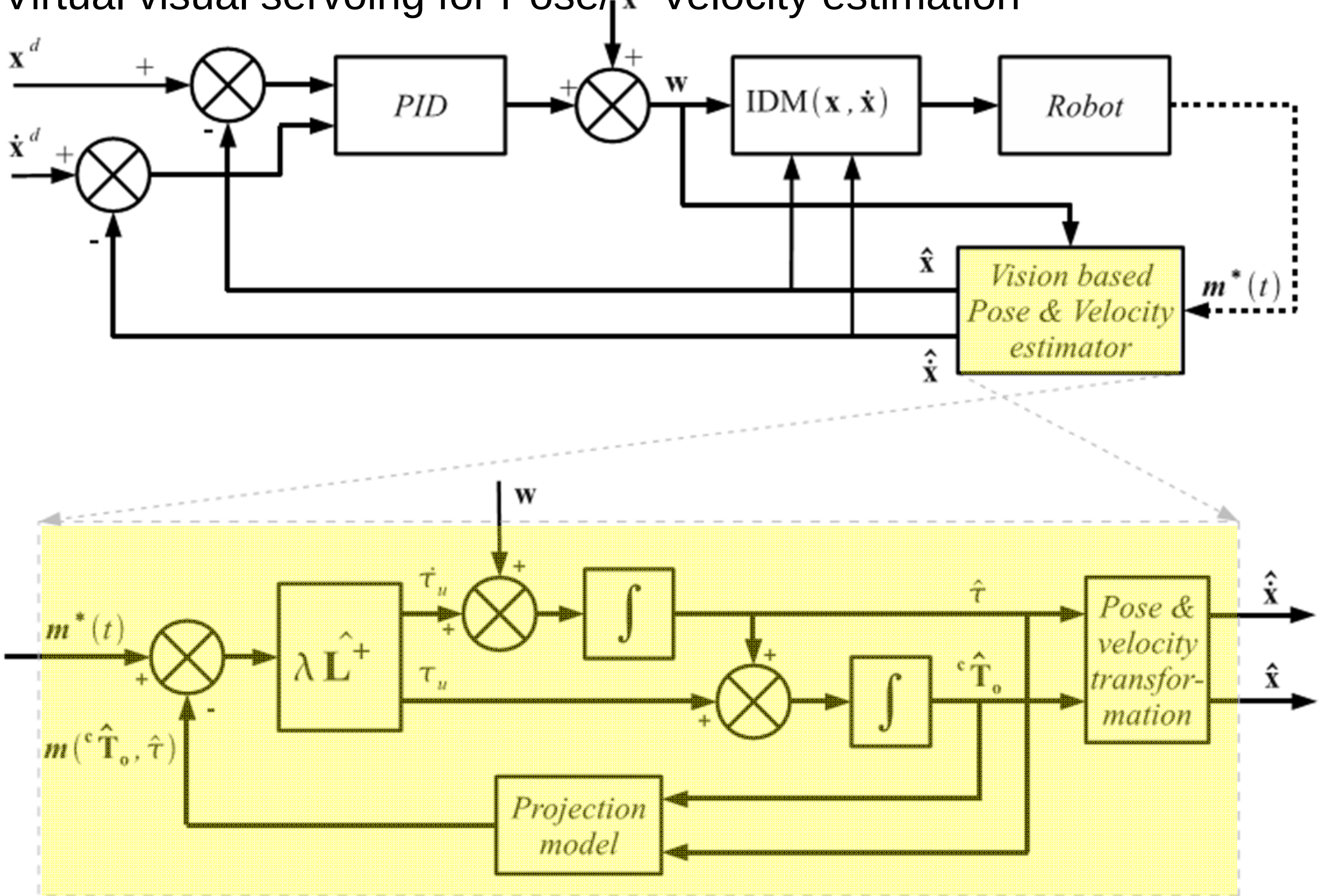
$$\dot{E} = -\lambda E$$

$$\dot{q} = -\lambda {}^m D_m^{inv} {N^T}^+ E$$

Dynamic Cartesian Based control

[Dahmouche10,12]

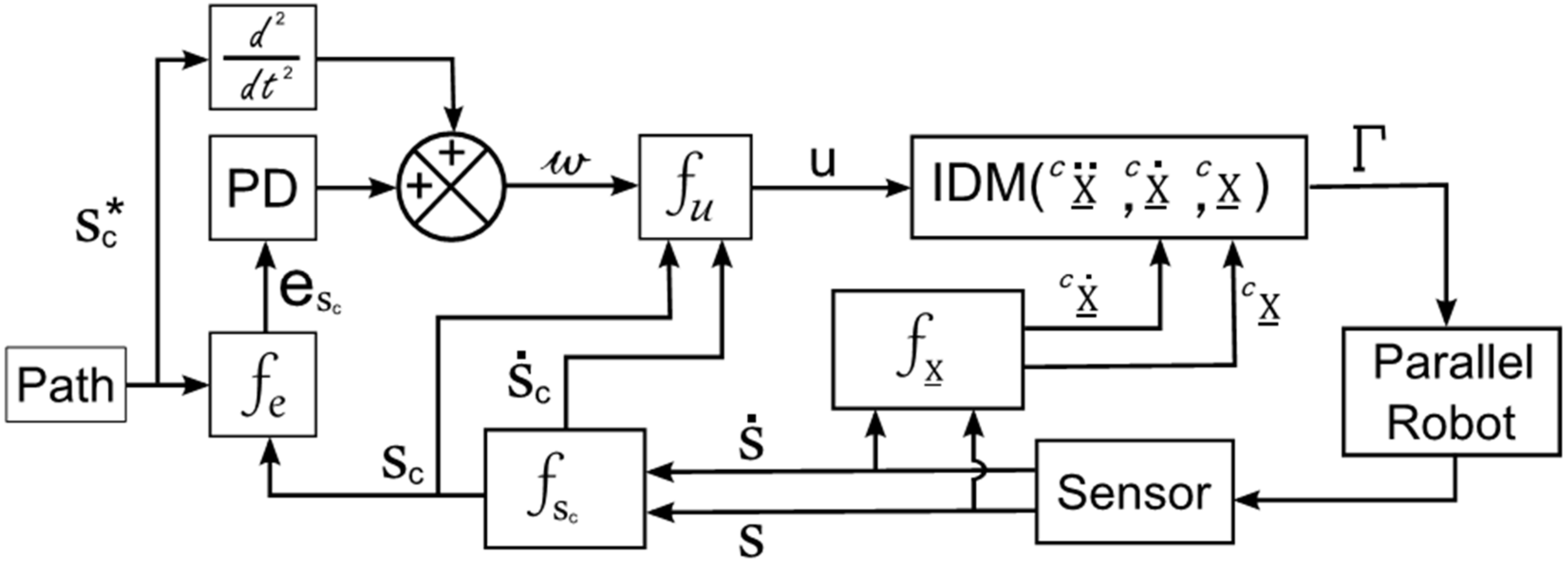
Virtual visual servoing for Pose/ Velocity estimation



Dynamic Sensor Based Control

[Özgür10]

Generic Control Space



- CTC* in the legs direction space (LS-CTC) $\mathbf{u}, \dot{\mathbf{u}}$
- CTC* in cartesian space (CS-CTC) $\mathbf{X}, \dot{\mathbf{X}}$
- CTC* in image space (Edges) (ES-CTC) $\mathbf{n}, \dot{\mathbf{n}}$ [Özgür11]

$$\mathbf{e} = f_e(\mathbf{s}^*, \mathbf{s}) = \mathbf{s}^* - \mathbf{s}$$

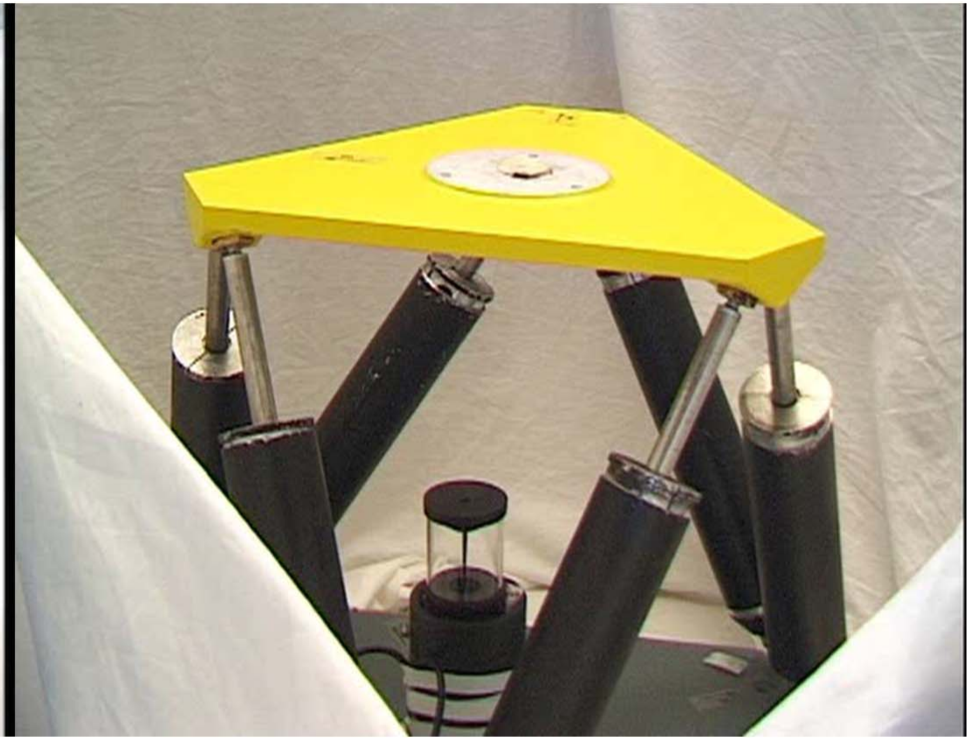
$$\mathbf{u} = f_u(\mathbf{L}_s,\ \dot{\mathbf{L}}_s, \dot{\mathbf{s}}, \omega) = \dot{\mathbf{L}}_s\dot{\mathbf{s}} + \mathbf{L}_s\,\omega$$

**CTC : Computed Torque control*

Kinematic Vision Based Control of Gough Stewart Platform

[Andreff05]

[Tahri07]

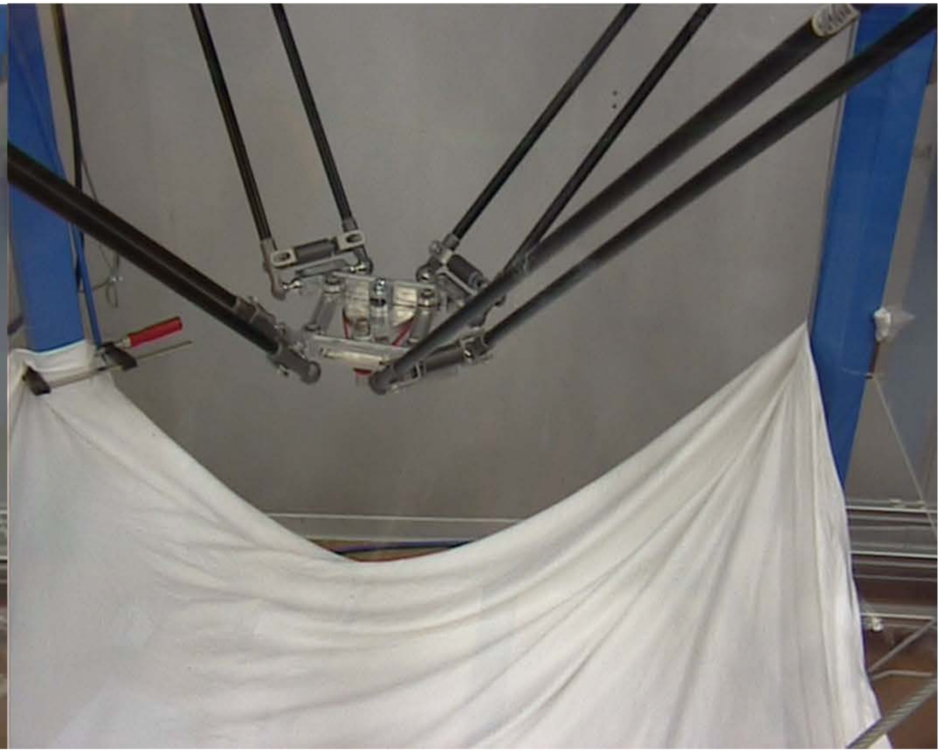


Control of parallel robot using legs observation

Kinematic Vision Based Control of Gough Stewart Platform

[Dalle06]

[Dallej06]

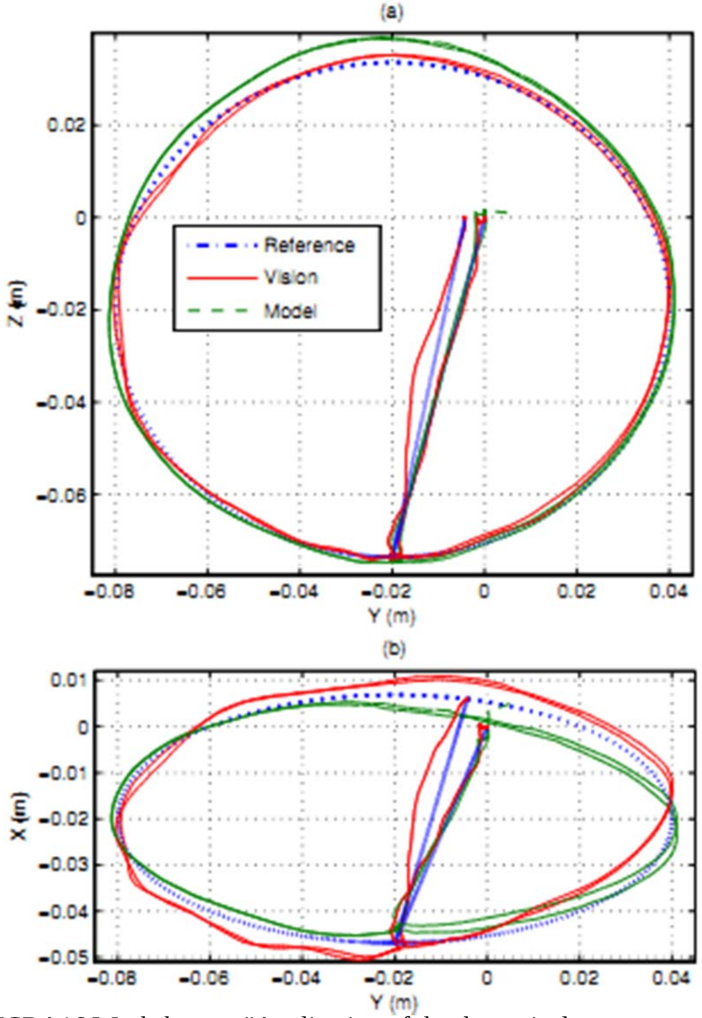


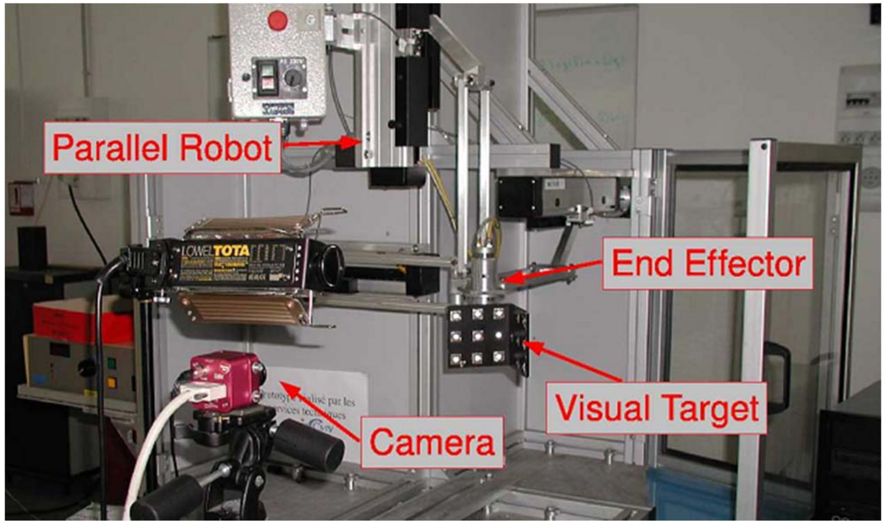
Control of parallel robot using legs observation

Dynamic Cartesian Based control

[Dahmouche10]

Dynamic control of orthoglide at 400Hz (Acquisition 4khz, CMOS Camera)





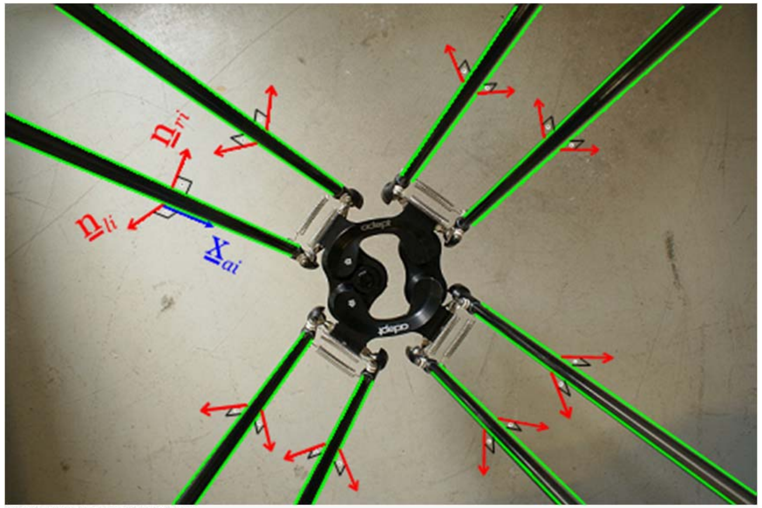
First time that we show that Dynamic Vision Based Control is better than Dymanic Model Based Control

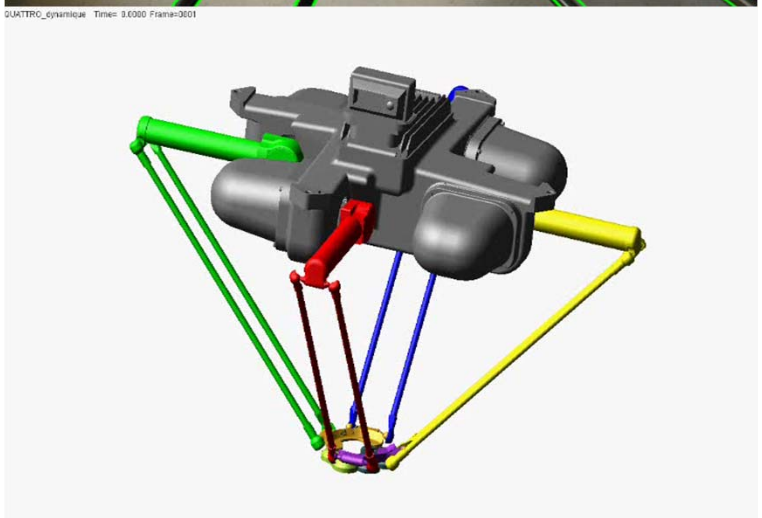
Dynamic Cartesian Based control [Dahmouche10]

Dynamic control of orthoglide at 400Hz (Acquisition 4khz, CMOS Camera)

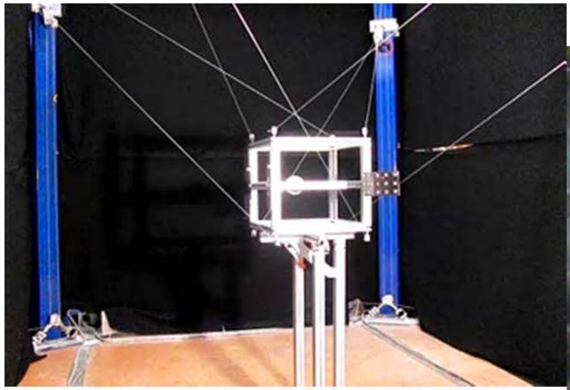
Dynamic Vision Based Control of Quattro robot

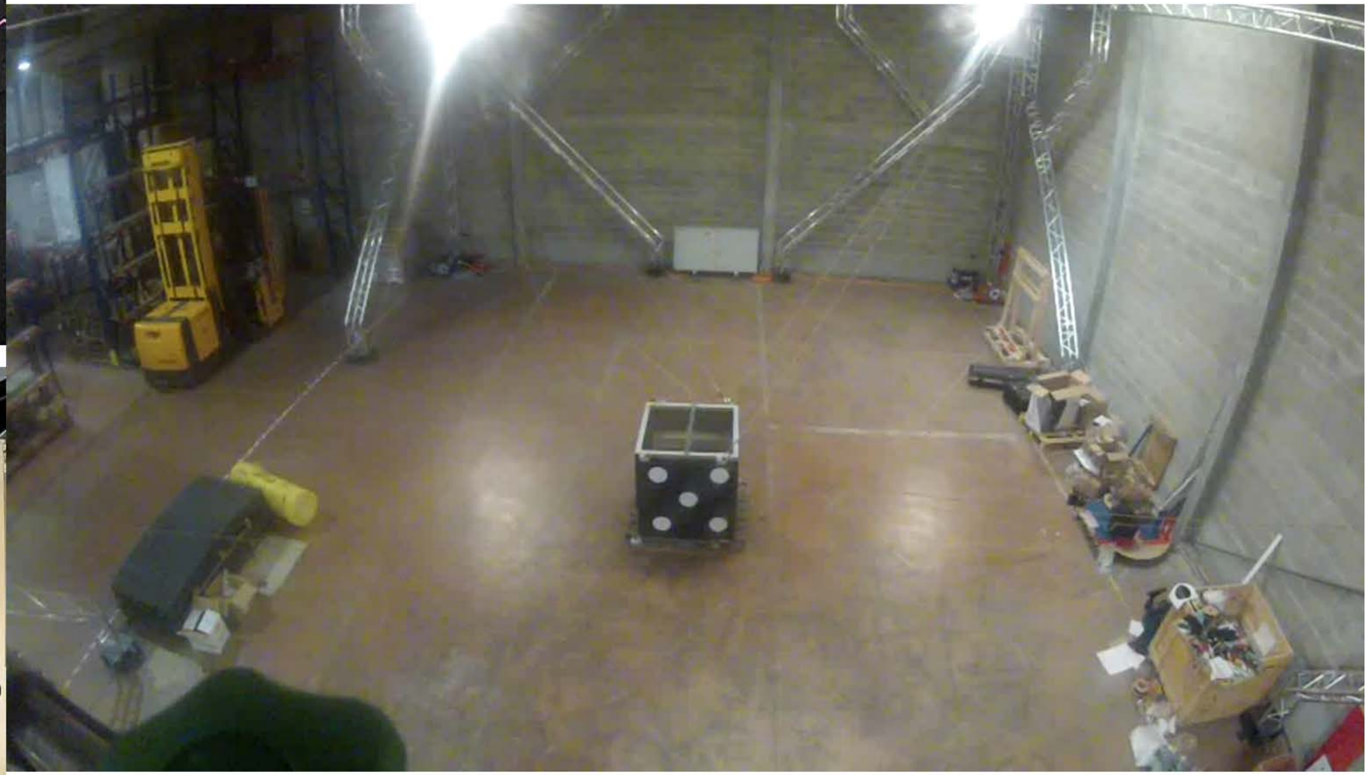
[Özgür10]





Vision Based Control of Parallel cable driven robot [Dallej11, Dallej12]

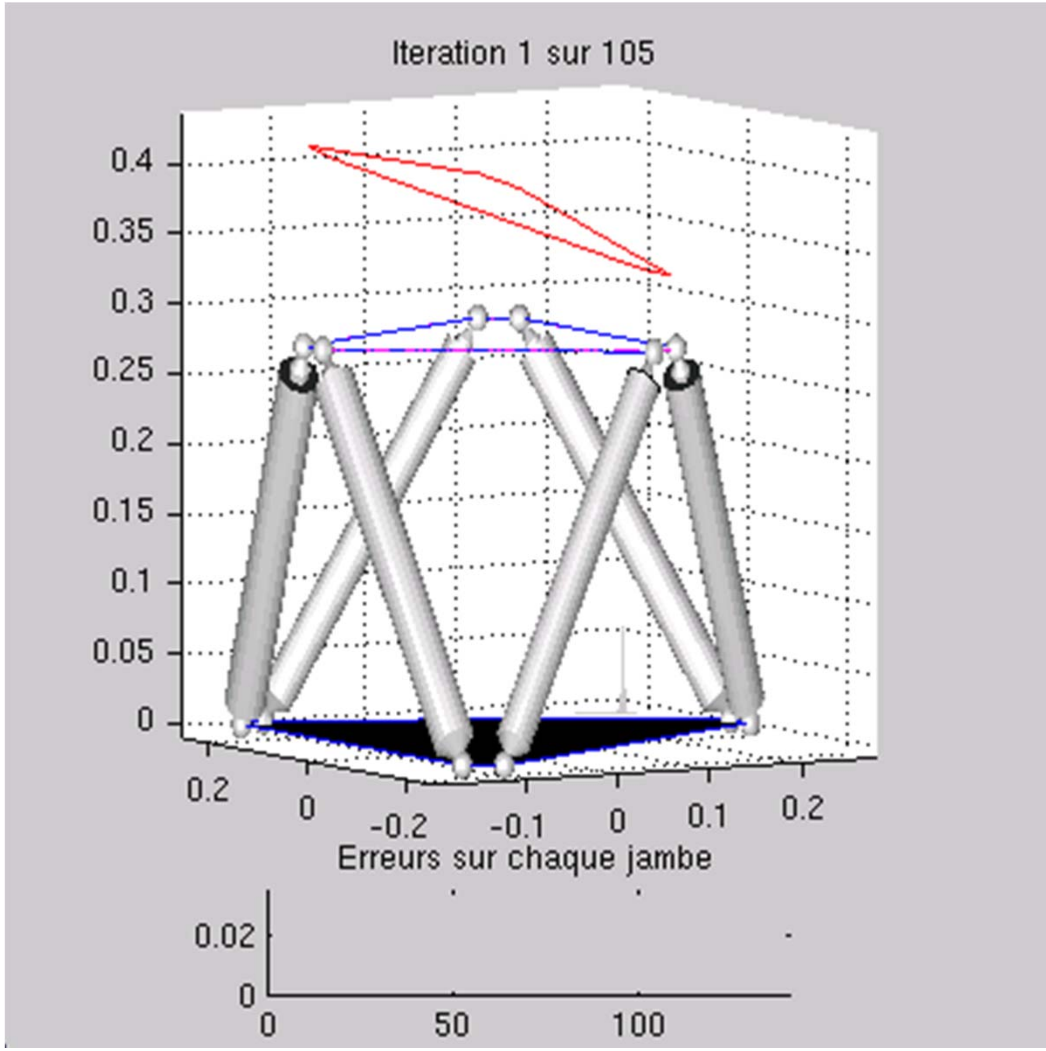




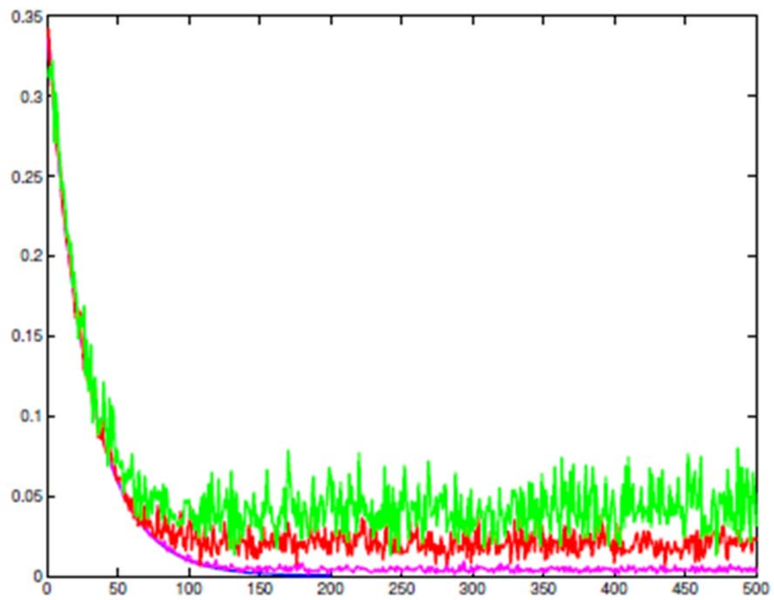
Real Axe8
COGIRO project 2011

Large-Dimension Cable-Driven Parallel Robots
COGIRO project 2012

Some problems and questions in Kinematic Vision Based Control



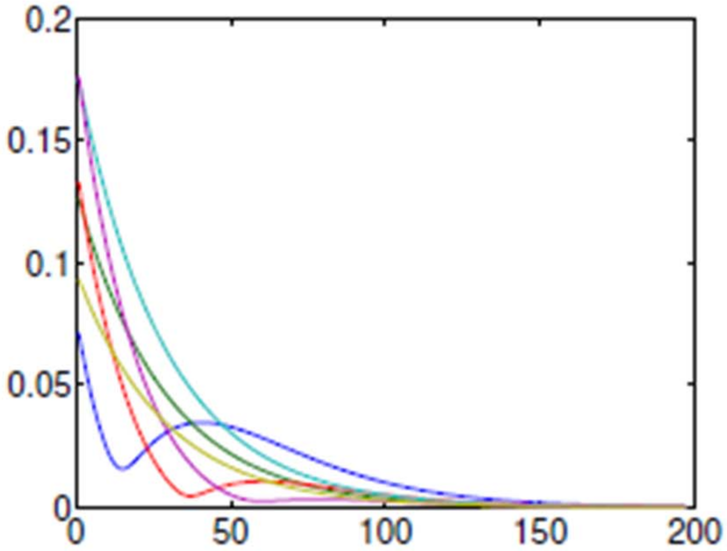
[Andref05]

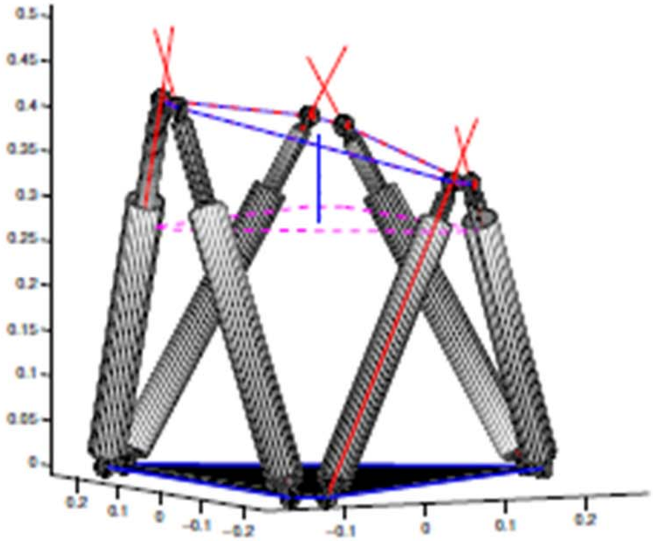


Robustness to noise : sum of squares of the errors E^TE *vs* time with a noise amplitude of 0.01 deg (dashed), 0.05 deg (dashed) and 0.1 deg (dash-dotted).

Some problems and questions in Kinematic Vision Based Control

[Andref05]



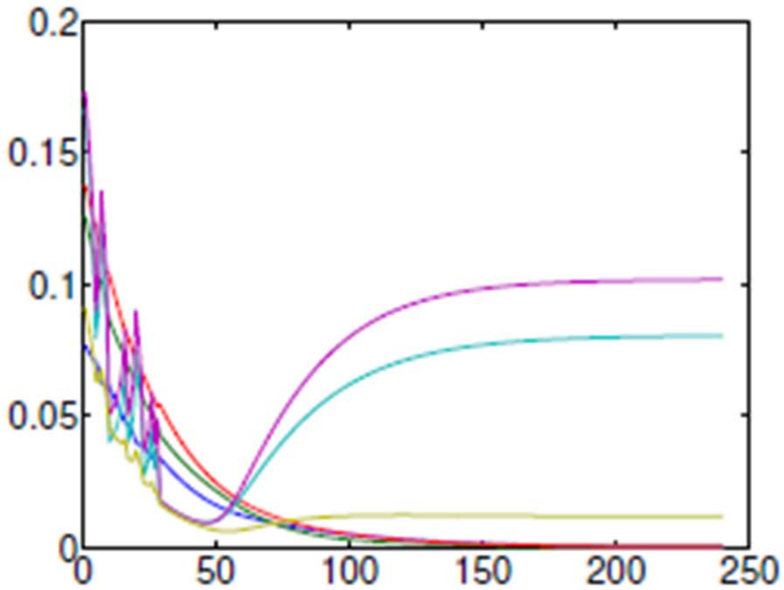


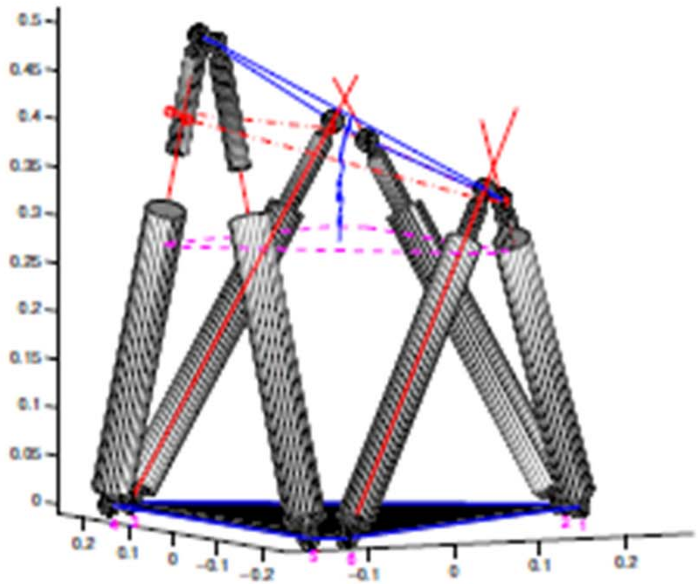
Lucky convergence in the case where legs 2, 4 and 6 only are used for control

3 legs represents 3*2 d.o.f controlled

Does the 3 selected legs directions represent the state of the Robot?

Some problems and questions in Kinematic Vision Based Control





[Andref05]

Non-convergence in the case where legs 1, 2 and 3 only are used for control. The direction of the legs are superimposed (red) on the cylinders. A leg has converged to its desired orientation if its direction crosses the endeffector in the desired pose at the joint location. Notice that this happens only for the 3 controlled legs.

3 legs represents 3*2 d.o.f controlled. The 3 other legs converge to another equilibrium

How to choose the right set of 3 legs?

Why we are converging to another cartesian pose?

Some problems and questions in Kinematic Vision Based Control

What is the state of a parallel robot?

How to choose the right set of legs? (for control? For end effector pose estimation?)

Why we are converging to another cartesian pose?

Part II The concept of Hidden Robot

- *Concept of Hidden Robot*
- *Controllability analysis*
- *Extension of the concept*
- *Conclusion*