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

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**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 kinematic/dynamic?
- Is it accurate enough?
- Does it work in a large workspace?

Can we define a generic and integrated formalism for Modelling/Identification and Control (MICMAC) for complex MAChines (Parallel robots)? In kinematic? … Dynamic?
Research done at LASMEA 2000-2011 (Pascal Institute in Clermont-Fd)

Introducing advanced control of parallel robots and its extension to other research fields

The concept of "Hidden Robot"

Projects

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

Vision Based Control

Application to Parallel Robot

Illustrations

**ICRA16 Workshop on “Application of the theoretical background in Parallel Robotics to other research areas”**

P. Martinet, S. Briot  
ICRA16, Stockholm, May 16th 2016

**Vision Based Control Application to Parallel Robot Illustrations**

Introduction

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**Case of embedded camera**

\[ s = s(x, t) \]

\[ \dot{s} = \begin{bmatrix} \frac{\partial s}{\partial x} \\ \frac{\partial s}{\partial t} \end{bmatrix} \begin{bmatrix} dx \\ dt \end{bmatrix} + \frac{\partial s}{\partial t} \]

\[ \dot{s} = L_s v + \frac{\partial s}{\partial t} \]

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

\[ \dot{s} = L_s v \]
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/2DHybrid

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
Generally, we define a task error, and we impose an exponential decrease of the error which gives a proportional control law:

\[
\begin{align*}
\dot{s} &= L_s v \\
e &= C(s(t) - s^*) \\
\dot{e} &= -\lambda e \\
v &= -\lambda L_s^+(s(t) - s^*)
\end{align*}
\]

\(e\) 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).

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**Serial robots and parallel robots**

<table>
<thead>
<tr>
<th>Serial robots</th>
<th>Parallel robots</th>
</tr>
</thead>
<tbody>
<tr>
<td>(q \Rightarrow X)</td>
<td>(X \Rightarrow q)</td>
</tr>
<tr>
<td><strong>Kinematic Modelling</strong></td>
<td><strong>Jacobians</strong></td>
</tr>
<tr>
<td>(q = f(q))</td>
<td>(X = f(X))</td>
</tr>
<tr>
<td>(g(q))</td>
<td>(g(X))</td>
</tr>
<tr>
<td>(f(q) \Rightarrow g(q) = f^{-1}(q))</td>
<td>(g(X) \Rightarrow f(X) = g^{-1}(X))</td>
</tr>
<tr>
<td><strong>Jacobian Matrix</strong></td>
<td><strong>(J_{inv})</strong></td>
</tr>
<tr>
<td>(\dot{q} \Rightarrow \dot{X})</td>
<td>(\dot{X} \Rightarrow \dot{q})</td>
</tr>
<tr>
<td>(\dot{X} = J(q)q)</td>
<td>(\dot{q} = J_{inv}(X)\dot{X})</td>
</tr>
<tr>
<td>(J(q) \Rightarrow J^{-1}(q))</td>
<td>(J_{inv}(X) \Rightarrow J^{-1}_{inv}(X))</td>
</tr>
</tbody>
</table>
Kinematic Vision-based control using leg observation

*Case of a Gough Stewart platform*

\[ \dot{q}^m = D_{m}^{\text{inv}} \cdot \tau_m \]

\[ m\dot{u}_i = M_i^T \tau_m \]

\[ M_i^T = \begin{bmatrix} -\frac{1}{q_i} (I_3 - m u_i^T u_i^T) \end{bmatrix} \begin{bmatrix} I_3 & -[m A_0]^T \end{bmatrix} \]

\[ \dot{e}_i = -[m u_{d_i}] \times m \dot{u}_i \]

\[ E = (e_1^T, ..., e_6^T)^T \]

\[ \dot{E} = -\lambda E \]

Dynamic Cartesian Based control

Virtual visual servoing for Pose/Vel estimation

[Dahmouche10,12]

[Ait-Aider06] ECCV06 Longuet Higgins Award
Dynamic Sensor Based Control

Generic Control Space

- CTC* in the legs direction space (LS-CTC) \( u, \dot{u} \)
- CTC* in cartesian space (CS-CTC) \( x, \dot{x} \)
- CTC* in image space (Edges) (ES-CTC) \( n, \dot{n} \)

\[ e = f_e(s^*, s) = s^* - s \]
\[ u = f_u(L_3, L_\alpha, s, \omega) = L_3 s + L_\alpha \omega \]

*CTC : Computed Torque control

Kinematic Vision Based Control of Gough Stewart Platform

Control of parallel robot using legs observation
Kinematic Vision Based Control of Gough Stewart Platform

Control of parallel robot using legs observation

Dynamic Cartesian Based control

First time that we show that Dynamics Vision Based Control is better than Dynamics Model Based Control
Dynamic Cartesian Based control

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

Dynamic Vision Based Control of Quattro robot

[Özgür10]
Vision Based Control of cable driven Parallel robot [Dallej11, Dallej12]

Real Axe8
COGIRO project 2011

Large-Dimension Cable-Driven Parallel Robots
COGIRO project 2013

Some problems and questions in Kinematic Vision Based Control

Case of a Gough Stewart platform [Andref05]

Robustness to noise : sum of squares of the errors $E^T E$ 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

Case of a Gough Stewart platform

[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 represent 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? Is it the legs space?

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

Why we are converging to another cartesian pose?

Is it possible to better understand the mapping characteristics?

Part II The concept of Hidden Robot

– Concept of Hidden Robot
– Controllability analysis
– Extension of the concept
– Conclusion