Improving the Dynamics Performance of Fast Robot Manipulators

Own results and future challenges

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Introduction

Fast Robot Manipulators?
Fast Robot Manipulators?

In the large majority $\Rightarrow$ Parallel Robots
Introduction

Fast Robot Manipulators?

In the large majority ⇒ Parallel Robots

Most of my work is on parallel robots (but not restricted to!)
Introduction

Why parallel robots?

Known advantages

- high payload-to-weight ratio
- high intrinsic stiffness
- large number of architectures (versatility)
- high acceleration capacities
Introduction

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No concurrents

Fastest robots
Introduction

No concurrents

Fastest robots

- Serial robot: Staübli’s FAST Picker (about 10 G)
Introduction

No concurrents
Fastest robots
  • Serial robot: Staëlbi’s FAST Picker (about 10 G)
  • Parallel Robot: R4 from LIRMM (> 100 G)
Main keywords in articles on parallel robots
Introduction

Few works on dynamics of parallel robots

Is everything done?
Introduction

Few works on dynamics of parallel robots

Is everything done?

DYNAMICS’ NOT DEAD!
Introduction

Few works on dynamics of parallel robots

Is everything done?

DYNAMICS’ NOT DEAD!

- Dynamics vs. accuracy
- Dynamics singularities
- Vibrations
- Dynamics vs. energy consumption
- Dynamics vs. human safety
- Fast robots mounted on mobile, flying, swimming ... robots
Introduction

Few works on dynamics of parallel robots

Is everything done?

DYNAMICS’ NOT DEAD!

- Dynamics vs. accuracy
- Dynamics singularities
- Vibrations
- Dynamics vs. energy consumption
- Dynamics vs. human safety
- Fast robots mounted on mobile, flying, swimming … robots
Outline of the presentation

1. Degeneracy conditions of the dynamic model of parallel robots
2. Design and control of high-speed and high-accuracy robots
3. Other works on dynamics
4. Future challenges and conclusions
Degeneracy of the dynamics in Type 2 singularities

Generic parallel robot

![Diagram of a generic parallel robot with symbolic notation and labels indicating base fixe, plate-forme mobile, articulation i3, corps B_i3, and base fixe.]
Degeneracy of the dynamics in Type 2 singularities

Inverse dynamic model

\[ \tau = w_b - B_p^T \lambda \]
\[ A_p^T \lambda = w_p \quad \text{with} \quad A_p \dot{x} + B_p \dot{q}_a = 0 \implies \tau = w_b - B_p^T A_p^{-T} w_p \quad (1) \]

\( \dot{x} \): derivative of the platform configuration (NOT the platform twist)

\( \dot{q}_a \): active joint velocities

\[ w_b = \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_a} \right) - \frac{\partial L}{\partial q_a} \]

\[ w_p = \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{x}} \right) - \frac{\partial L}{\partial x} \]
Degeneracy of the dynamics in Type 2 singularities

Inverse dynamic model

$$\tau = w_b - B_p^T \lambda$$

with

$$A_p \dot{x} + B_p \dot{q}_a = 0 \Rightarrow \tau = w_b - B_p^T A_p^{-T} w_p$$  \hspace{1cm} (1)

$\dot{x}$: derivative of the platform configuration (NOT the platform twist)

$\dot{q}_a$: active joint velocities

$$w_b = \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_a} \right) - \frac{\partial L}{\partial q_a}$$

$$w_p = \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{x}} \right) - \frac{\partial L}{\partial x}$$

Thus,

The dynamic model is proportional to $\frac{1}{\det(A_p)}$
Degeneracy of the dynamics in Type 2 singularities

Inverse dynamic model

\[ \tau = w_b - B^T_p \lambda \]
\[ A_p^T \lambda = w_p \]

with

\[ A_p \dot{x} + B_p \dot{q}_a = 0 \Rightarrow \tau = w_b - B^T_p A_p^{-T} w_p \] (1)

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\[ w_p = \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{x}} \right) - \frac{\partial L}{\partial x} \]

So, if \( \text{det}(A_p) = 0 \), (Type 2 sing. [Gosselin & Angeles 1990])

- **Near singularities, \( \tau \rightarrow \infty \)**
- Dynamic model degeneracy = **Impossible to cross sing.**
Why crossing Type 2 singularities is appealing?

[Bonev 2002]
Why crossing Type 2 singularities is appealing?

[Bonev 2002]
Degeneracy of the dynamics in Type 2 singularities

Inverse dynamic model

\[ \tau = w_b - B_p^T A_p^{-T} w_p \]  \hspace{1cm} (2)

Contribution

Dynamics does not degenerate in Type 2 singularity iff

\[ t_s^T w_p = 0, \]  \hspace{1cm} (3)

with \( t_s \) defined by \( A_p t_s = 0 \), \hspace{1cm} (4)
Degeneracy of the dynamics in Type 2 singularities

**Contribution**
Dynamics does not degenerate in Type 2 singularity iff

\[ t_s^T w_p = 0, \]  \hspace{1cm} (2)

with \( t_s \) defined by

\[ A_p t_s = 0, \]  \hspace{1cm} (3)

\[ \Rightarrow \text{When the robot cross a Type 2 singularity, the wrenches applied on the platform (by the legs, the inertial effects, gravitation, external efforts) } w_p \text{ must be reciprocal to the uncontrollable platform motion } t_s \]
Degeneracy of the dynamics in Type 2 singularities

An illustrative example

In an arbitrary configuration

Equilibrium iff $w_p = r_1 + r_2$
Degeneracy of the dynamics in Type 2 singularities

An illustrative example

In singularity

\[ \mathbf{w}_p = \mathbf{r}_1 + \mathbf{r}_2 \] with

- \( \mathbf{r}_1 \times \mathbf{r}_2 = 0 \)
- \( \mathbf{t}_s^T \mathbf{r}_1 = \mathbf{t}_s^T \mathbf{r}_2 = 0 \) (\( \mathbf{t}_s \) uncontrollable motion)
Degeneracy of the dynamics in Type 2 singularities

An illustrative example

In singularity

\[ w_p = r_1 + r_2 \]  

with

- \( r_1 \times r_2 = 0 \)
- \( t_s T r_1 = t_s T r_2 = 0 \) (\( t_s \) uncontrollable motion)

Problem if \( t_s T w_p \neq 0 \)
Degeneracy of the dynamics in Type 2 singularities

An illustrative example

In singularity

\[ \mathbf{w}_p = \mathbf{r}_1 + \mathbf{r}_2 \]

with

- \( \mathbf{r}_1 \times \mathbf{r}_2 = 0 \)
- \( \mathbf{t}_s^T \mathbf{r}_1 = \mathbf{t}_s^T \mathbf{r}_2 = 0 \) (\( \mathbf{t}_s \) uncontrollable motion)

No problem if \( \mathbf{t}_s^T \mathbf{w}_p = 0 \)
Degeneracy of the dynamics in Type 2 singularities

Trajectories through Type 2 singularities
Require to respect the criterion $t_s^T w_p = 0$ in singularity
Degeneracy of the dynamics in Type 2 singularities

Trajectories through Type 2 singularities
Require to respect the criterion $t_s^T w_p = 0$ in singularity

Note that:

- $t_s$ depends on the robot configuration
- $w_p$ depends on the robot configuration, velocity and acceleration
Degeneracy of the dynamics in Type 2 singularities

Trajectories through Type 2 singularities
Require to respect the criterion $t_s^T w_p = 0$ in singularity
Degeneracy of the dynamics in Type 2 singularities

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Trajectories through Type 2 singularities
Require to respect the criterion $t_s^T w_p = 0$ in singularity

Criterion is not respected
Degeneracy of the dynamics in Type 2 singularities

**Trajectories through Type 2 singularities**

Require to respect the criterion $t_s^T w_p = 0$ in singularity

Criterion is respected
Degeneracy of the dynamics in Type 2 singularities

Robustness issues
Can be manage through a proper Computed Torque Controller (CTC) [Pagis et al 2015]
Degeneracy of the dynamics in Type 2 singularities

Robustness issues
Can be manage through a proper Computed Torque Controller (CTC) [Pagis et al 2015]
To develop it, we impose a trajectory with $w_p = 0$ at singularity (respects $t_s^T w_p = 0$)
Degeneracy of the dynamics in Type 2 singularities

Robustness issues
Can be managed through a proper Computed Torque Controller (CTC) [Pagis et al. 2015]

TRAVERSEE Type 2
Degeneracy of the dynamics in Type 2 singularities

Conclusions

• Definition of dynamic model degeneracy conditions...
Degeneracy of the dynamics in Type 2 singularities

Conclusions

- Definition of dynamic model degeneracy conditions...
- ... and of trajectories for avoiding this degeneracy
Degeneracy of the dynamics in Type 2 singularities

Conclusions

• Definition of dynamic model degeneracy conditions...
• ... and of trajectories for avoiding this degeneracy
• Definition of a dedicated controller (collaboration IFMA)
Degeneracy of the dynamics in Type 2 singularities

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- Validation with several robots (planar: Five-bar mech. / spatial: PAMINSA)
Degeneracy of the dynamics in Type 2 singularities

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• Work extended to flexible robots
Degeneracy of the dynamics in Type 2 singularities

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- Ongoing works: automation / certification
- Future works: Constraint sing. crossing, CDPM
Design / Control of fast and accurate robots

Design of a 2T robot for *pick-and-place* operations

**Advantages:**
- Intrinsic stiffness
- Smaller number of legs than the Par2
Design / Control of fast and accurate robots

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**Drawbacks:**
- Architecture complexity
- Singularities
Design / Control of fast and accurate robots

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**Drawbacks:**
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Work done in the scope of the French ANR project ARROW
Design / Control of fast and accurate robots

### Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of motion</td>
<td>2T 1R</td>
</tr>
<tr>
<td>Repeatability $\epsilon_{lim}$ in ($xOz$)</td>
<td>$20 \ \mu m$</td>
</tr>
<tr>
<td>Resolution $r_{lim}$</td>
<td>$2 \ \mu m$</td>
</tr>
<tr>
<td>Max. acceleration</td>
<td>$20 \ G$</td>
</tr>
<tr>
<td>Cycle time</td>
<td>$200 \ ms$</td>
</tr>
<tr>
<td>Path dimension</td>
<td>$25 \ mm \times 300 \ mm \times 25 \ mm$</td>
</tr>
<tr>
<td>Regular workspace size</td>
<td>$800 \ mm \times 100 \ mm$</td>
</tr>
<tr>
<td>Deformation $\delta_{t,lim}$ under a force $f_s = [0, 20, 0]$ N and a moment $m_s = [1, 1, 1]$ N.m</td>
<td>$[0.2, 0.2, 0.2] \ mm,$ $[0.1, 0.1, 0.1] \ deg$</td>
</tr>
<tr>
<td>Max. payload (including the embedded motor)</td>
<td>$1.5 \ kg$</td>
</tr>
<tr>
<td>Conception</td>
<td>$b b_w$ [m]</td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Jaune (♦)</td>
<td>0.20</td>
</tr>
<tr>
<td>Rose (+)</td>
<td>0.15</td>
</tr>
<tr>
<td>Orange (★)</td>
<td>0.15</td>
</tr>
<tr>
<td>Violet (▲)</td>
<td>0.15</td>
</tr>
<tr>
<td>Verte (■)</td>
<td>0.2</td>
</tr>
<tr>
<td>Bleu (▲)</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Optimisation results

<table>
<thead>
<tr>
<th>Conception</th>
<th>$b_{bw} ,[m]$</th>
<th>$M_{IRS} ,[kg]$</th>
<th>$F_{IRS}^{1} ,[Hz]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jaune (♦)</td>
<td>0.20</td>
<td>1.94</td>
<td>41.9</td>
</tr>
</tbody>
</table>
IRSBot-2 prototype

Tecnalia

- $\delta_{ty} < 0.17$ mm
- $f_{IRS}^1 = 44.9$ Hz (in the plane)
- $f_{IRS}^2 = 55$ Hz (out the plane)
IRSBot-2 prototype
Design / Control of fast and accurate robots

Repeatability performance

30 microns in the dexterous regular workspace
Design / Control of fast and accurate robots

Static deformations
Design / Control of fast and accurate robots

Static deformations

120 microns in the dexterous regular workspace under a load of 20 N along $y_0$
Design / Control of fast and accurate robots

Natural frequencies
**Design / Control of fast and accurate robots**

### Natural frequencies

<table>
<thead>
<tr>
<th>Calculées par CAO</th>
<th>Obtenues par sonnage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td><strong>Displacement mode</strong></td>
</tr>
<tr>
<td>45 Hz</td>
<td>Perp. to motion</td>
</tr>
<tr>
<td>53 Hz</td>
<td>Plane of motion</td>
</tr>
<tr>
<td>60 Hz</td>
<td>Perp. to motion</td>
</tr>
</tbody>
</table>
Design / Control of fast and accurate robots

Dynamic performance

TRAVERSEE Type 2

20 G of acceleration, 6 m/s
Design / Control of fast and accurate robots

Dynamic performance

Tracking error divided by 20 between PID and CTC
Design / Control of fast and accurate robots

What is not mentioned

• Singularity analysis
Design / Control of fast and accurate robots

What is not mentioned

• Singularity analysis
• Modeling / Identification issues
Design / Control of fast and accurate robots

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- Singularity analysis
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Ongoing work

- Vibration control
Design / Control of fast and accurate robots

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• 3rd axis
Design / Control of fast and accurate robots

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• Vibration control
• 3rd axis
• Improving the absolute accuracy
Design / Control of fast and accurate robots

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Ongoing work

- Vibration control
- 3rd axis
- Improving the absolute accuracy
  - Mapping of error and use in control ($< 100$ microns)
Design / Control of fast and accurate robots

What is not mentioned

- Singularity analysis
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Ongoing work

- Vibration control
- 3rd axis
- Improving the absolute accuracy
  - Mapping of error and use in control (< 100 microns)
  - Sensor-based control
Design / Control of fast and accurate robots

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- Improving the absolute accuracy
  - Mapping of error and use in control (< 100 microns)
  - Sensor-based control
Design / Control of fast and accurate robots

Vision-based control of fast and accurate robots
Different possible approaches

- direct observation of the end-effector [Paccot et al., 2008]
Design / Control of fast and accurate robots

Vision-based control of fast and accurate robots
Different possible approaches

• observation of legs [Özgür et al., 2011]
Design / Control of fast and accurate robots

Vision-based control of fast and accurate robots
Different possible approaches

- **observation of legs** [Özgür et al., 2011]
Leg-direction-based visual servoing

Issues / Questions

• the observation of $m$ leg directions ($m < n$) among the $n$ legs is enough,
Leg-direction-based visual servoing

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• convergence problems for the end-effector, even if there is convergence of the leg directions
Leg-direction-based visual servoing

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- the observation of $m$ leg directions ($m < n$) among the $n$ legs is enough,
- convergence problems for the end-effector, even if there is convergence of the leg directions
- existence of local minima
Leg-direction-based visual servoing

Issues / Questions

• the observation of $m$ leg directions ($m < n$) among the $n$ legs is enough,
• convergence problems for the end-effector, even if there is convergence of the leg directions
• existence of local minima
• singularities of the model (between the leg space and the Cartesian space)
Leg-direction-based visual servoing

Possible to answer to these questions thanks to the concept of “Hidden Robot”
Leg-direction-based visual servoing

Possible to answer to these questions thanks to the concept of “Hidden Robot”

Basic idea
We must understand that, intrinsically, controlling the robot by observing its legs is equivalent to control another architecture

\[ e = u - u_{\text{des}} \]  
\[ \dot{e} = -\lambda e \Rightarrow \dot{u} = -\lambda e \]  
\[ \tau = -\lambda M^T + e \Rightarrow \dot{q} = -\lambda J_{\text{inv}} M^T + e \]  
\[ \ddot{u} = M^T \tau \]
Leg-direction-based visual servoing

Possible to answer to these questions thanks to the concept of “Hidden Robot”

Basic idea
We must understand that, intrinsically, controlling the robot by observing its legs is equivalent to control another architecture

\[ e = u - u_{des} \quad (4) \]

\[ \dot{e} = -\lambda e \Rightarrow \dot{u} = -\lambda e \quad (5) \]

\[ \tau = -\lambda M^T + e \Rightarrow \dot{q} = -\lambda J_{inv} M^T + e \quad (6) \]

\[ \dot{u} = M^T \tau \quad (7) \]
Leg-direction-based visual servoing

Basic idea
We must understand that, intrinsically, controlling the robot by observing its legs is equivalent to control another architecture.

Usual encoder-based controller
\[ q \Rightarrow x \ (q: \text{measurement corresponding to the real actuators}) \]
Leg-direction-based visual servoing

Basic idea
We must understand that, intrinsically, controlling the robot by observing its legs is equivalent to control another architecture

Leg-direction-based visual controller
\[ \mathbf{u} \Rightarrow \mathbf{x} \ (\mathbf{u}: \text{corresponding to the virtual actuators of the hidden robot}) \]
Leg-direction-based visual servoing

Leg-direction-based visual controller

Gough-Stewart platform:

- Real robot $\Rightarrow$ 6–UPS
Leg-direction-based visual servoing

Leg-direction-based visual controller

Gough-Stewart platform:

- Real robot $\Rightarrow$ 6-UPS
- Hidden (virtual) robot $\Rightarrow$ 3-UPS (case of the minimal observation)
Leg-direction-based visual servoing

Leg-direction-based visual controller

Gough-Stewart platform:

- Real robot $\Rightarrow$ 6–UPS
- Hidden (virtual) robot $\Rightarrow$ 3–UPS (case of the minimal observation)
Leg-direction-based visual servoing

Leg-direction-based visual controller

Gough-Stewart platform:

- Real robot $\Rightarrow$ 6–UPS
- Hidden (virtual) robot $\Rightarrow$ 3–UPS (case of the minimal observation)
Leg-direction-based visual servoing

By considering this analogy
Leg-direction-based visual servoing

By considering this analogy

⇒ Final (non-desired) platform location ≡ a solution of the FGM of the 3–UPS robot in the same aspect as the initial configuration
Leg-direction-based visual servoing

By considering this analogy
⇒ Able to explain why the observation of \( m \) leg directions \( (m < n) \) among the \( n \) legs is enough
⇒ Find the local minima
⇒ Find the singularities of the model used in the visual servoing
Generalization of the concept and application to different robot classes

Planar robots

Example of the 3-RRR robot
Generalization of the concept and application to different robot classes

Planar robots

Example of the 3–RRR robot
Generalization of the concept and application to different robot classes

Planar robots

Example of the 3–RRR robot

Vertex spaces for legs 1 and 2

Coupler curve

Vertex space for leg 3
Generalization of the concept and application to different robot classes

Spatial robots

Example of the Adept Quattro
Generalization of the concept and application to different robot classes

Spatial robots

Example of the Adept Quattro
Generalization of the concept and application to different robot classes

Spatial robots

Example of the Adept Quattro
Generalization of the concept and application to different robot classes

Spatial robots

Example of the Adept Quattro

- Fixed base
- Uncontrolled platform motion
- $C_i$: vertical slice of the Bohemian Dome for a constant platform orientation
- Articulated moving platform
- $C_j$
Generalization of the concept and application to different robot classes

Experimental validation
Generalization of the concept and application to different robot classes

Experimental validation
Use of the concept of hidden robot for the controllability analysis

Definition of four main classes of robots for leg-direction-based controllers

**Cl 1:** Robots which are not controllable

**Cl 2:** Robots which are partially controllable in their whole workspace

**Cl 3:** Robots which are fully controllable in their whole workspace

**Cl 4:** Robots which becomes controllable by using additional measurements
Use of the concept of hidden robot for the controllability analysis

**Class 1:** Robots which are not controllable

A \textit{PRRRP} robot

Unconstrained translation

Hidden robot: a \textit{PRRRP} robot
Use of the concept of hidden robot for the controllability analysis

**Class 2:** Robots which are partially controllable in their whole workspace

⇒ because singularities of the hidden robot always divide the workspace into several aspects (unconnected areas)
Use of the concept of hidden robot for the controllability analysis

**Class 3:** Robots which are fully controllable in their whole workspace
Use of the concept of hidden robot for the controllability analysis

Class 4: Robots which becomes controllable by using additional measurements
Use of the concept of hidden robot for the controllability analysis

**Class 4:** Robots which becomes controllable by using additional measurements

A *PRRRP* robot

Hidden robot: a *PRRRP* robot
Design / Control of fast and accurate robots

Conclusions

• New “spatial” 2T robot architecture
Design / Control of fast and accurate robots

Conclusions

• New “spatial” 2T robot architecture
• Optimal design methodology for fast and accurate robots
Design / Control of fast and accurate robots

Conclusions

- New “spatial” 2T robot architecture
- Optimal design methodology for fast and accurate robots
- Improving the accuracy of high-speed robots
Design / Control of fast and accurate robots

Conclusions

• New “spatial” 2T robot architecture
• Optimal design methodology for fast and accurate robots
• Improving the accuracy of high-speed robots
• Definition of a tool for understanding the mapping characteristics of some visual servoing
Ongoing and future works

Use of the concept of hidden robot for the visual servoing of multi-arm robots
Ongoing and future works

Use of the concept of hidden robot for the visual servoing of geometric primitives

\[
\begin{align*}
\mathcal{L}_1 & \quad \mathcal{L}_3 & \quad \mathcal{L}_2 \\
M_1 & \quad M_3 & \quad M_2 \\
m_1 & \quad m_3 & \quad m_2 \\
C &
\end{align*}
\]
Ongoing and future works

Use of the concept of hidden robot for the visual servoing of geometric primitives

The three active cardan joints are grouped at the same point

Passive prismatic joints

Passive spherical joints

The three active cardan joints are grouped at the same point
Ongoing and future works

Use of the concept of hidden robot for the visual servoing of geometric primitives
Ongoing and future works

Use of the concept of hidden robot for the visual servoing of geometric primitives
Ongoing and future works

Use of the concept of hidden robot for control-based design
Summary of other past works

Identification of dynamic parameters
Methodologies for the identification of dynamic parameters
- including the driving gains
- for overactuated robots
Summary of other past works

Elastodynamic modelling

Systematic / automatic procedure for the symbolic computation of the elastodynamic model of parallel robots
Summary of other past works

Balancing techniques

- dynamics (by optimal design, by optimal motion planning, etc.)
- statics (for high-load carrying robots)
Summary of other past works

Design of robots for high-load carrying
New parallel robot families with decoupled motions between

• planar platform motions
• vertical platform translations
Summary of other past works

Design of robots for high-load carrying
New parallel robot families with decoupled motions between

- planar platform motions
- vertical platform translations

![Graph 1](image1.png)

![Graph 2](image2.png)
Next challenges

Flying parallel robots

Interests:
- Sharing the load
- Rigid links vs cables $\Rightarrow$ work also in compression (apply forces on the environment)
Next challenges

Flying parallel robots

Keypoints:

- Management of overconstraint (relative motion between drones = 2 dof)
- Dynamic reconfiguration
Next challenges

Flying parallel robots

Next challenges

Drastic energy consumption reduction of high-speed robots

- High energy consumption
- No “relevant” solution
Next challenges

Drastic energy consumption reduction of high-speed robots

- A first step made in that direction via the use of springs

[Uemura et al. 2011]
[Iwamura et al. 2016]
Next challenges

**Drastic energy consumption reduction of high-speed robots**

- A first step made in that direction via the use of springs
- But
  - “Big” issues of accuracy
  - Just for few trajectories
  - Slow motions (cycle times > 10 sec)

[Uemura et al. 2011]
[Iwamura et al. 2016]
Next challenges

Drastic energy consumption reduction of high-speed robots
PhD Thesis of Rafael Balderas Hill (2016 ??– xxxx)
Next challenges

Design of a lightweight fast manipulator mounted on drones for grasping of moving objects

TRAVERSEE Type 2
Next challenges

Design of a lightweight fast manipulator mounted on drones for grasping of moving objects

Do the same with a manipulator mounted on a drone

- Issues of energy consumption
- Issues of drone stability when the manipulator is moving (at high speed)
- Issues of drone payload capacity
Next challenges

**Design of a lightweight fast manipulator mounted on drones for grasping of moving objects**

Work both on

⇒ Novel actuation systems (small powerless actuators vs high acceleration)

⇒ Topological optimization of robots
Next challenges

Design of a lightweight fast manipulator mounted on drones for grasping of moving objects

ANR DOS-COM ?? (IRCCyN, Heudiasyc, Gipsa-lab)
Next challenges

Other next works

- Eco-design of robots
- Singularity analysis for generic sensor-based controllers
- Control-based design
To conclude

Two messages to leave

• Dynamics’ not dead!
  (Especially for the design of fast robot manipulators)
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  *(Especially for the design of fast robot manipulators)*
- Mechanics’ not dead!
  - Control cannot solve all issues
  - Many tools used by mechanical engineers can solve tricky issues of control engineering community
These works were done in collaboration with

**Permanent researchers**
IRCCyN
- P. Martinet, M. Gautier, S. Caro, V. Arakelian, A. Chriette, W. Khalil

**Other labs**
- N. Bouton (SIGMA, ex IFMA), F. Chaumette (Irisa)
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