Advanced control of parallel robots and its extension to other research fields

The concept of "Hidden Robot"

Speakers:

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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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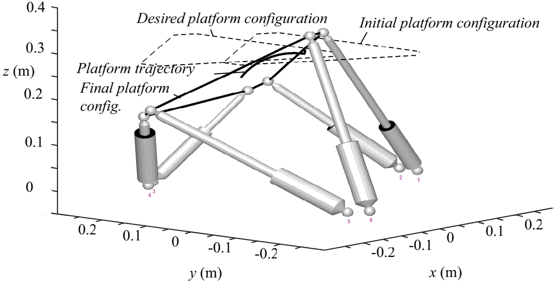
- convergence problems for the end-effector, even if there is convergence of the leg directions



Leg-direction-based visual servoing

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- convergence problems for the end-effector, even if there is convergence of the leg directions
- existence of local minima

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
- 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"

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Basic idea

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

$$\mathbf{e} = \underline{\mathbf{u}} - \underline{\mathbf{u}}_{des} \tag{1}$$

$$\dot{\mathbf{e}} = -\lambda \mathbf{e} \Rightarrow \dot{\underline{\mathbf{u}}} = -\lambda \mathbf{e} \tag{2}$$

$$\boldsymbol{\tau} = -\lambda \mathbf{M}^{T+} \mathbf{e} \Rightarrow \dot{\mathbf{q}} = -\lambda \mathbf{J}_{inv} \mathbf{M}^{T+} \mathbf{e} \tag{3}$$

$$\dot{\underline{\mathbf{u}}} = \mathbf{M}^{T} \boldsymbol{\tau} \tag{4}$$

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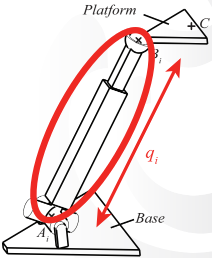
Usual encoder-based controller

$\mathbf{q} \Rightarrow \mathbf{x}$ ($\mathbf{q}$: measurement corresponding to the real actuators)



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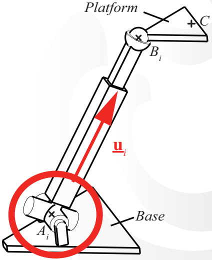
Leg-direction-based visual controller

$\underline{\mathbf{u}} \Rightarrow \mathbf{x}$ ($\underline{\mathbf{u}}$: corresponding to the virtual actuators of the hidden robot)



Leg-direction-based visual servoing

Leg-direction-based visual controller

Gough-Stewart platform:

- Real robot ⇒ 6–U$\underline{P}$S

Leg-direction-based visual servoing

Leg-direction-based visual controller

Gough-Stewart platform:

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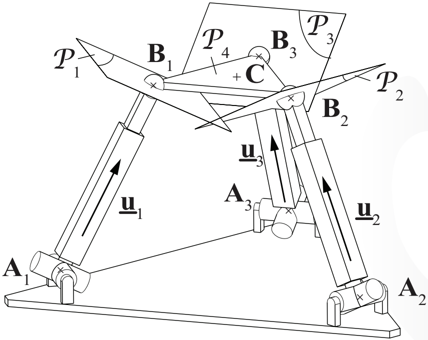
- Hidden (virtual) robot ⇒ 3–$\underline{\text{U}}$PS (case of the minimal observation)



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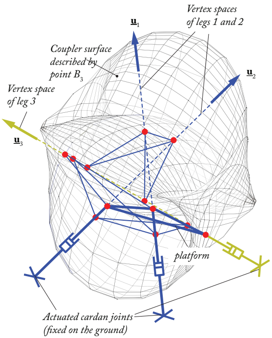

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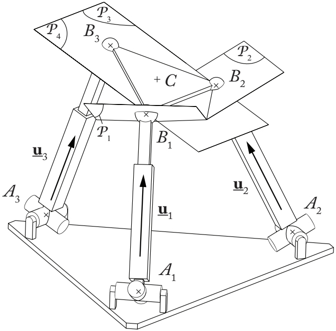


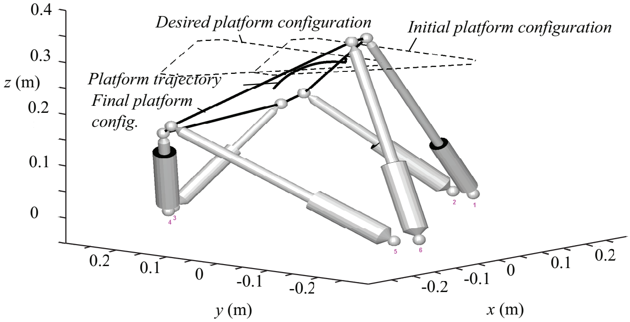
Leg-direction-based visual servoing

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–<u>U</u>PS robot in the same aspect as the initial configuration



Leg-direction-based visual servoing

By considering this analogy

$\Rightarrow$ Able to explain why the observation of m leg directions ($m < n$) among the n legs is enough

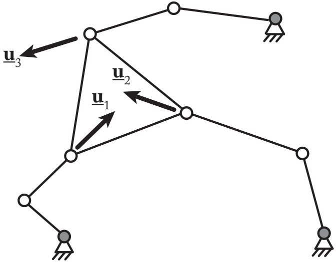
$\Rightarrow$ Find the local minima

$\Rightarrow$ 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



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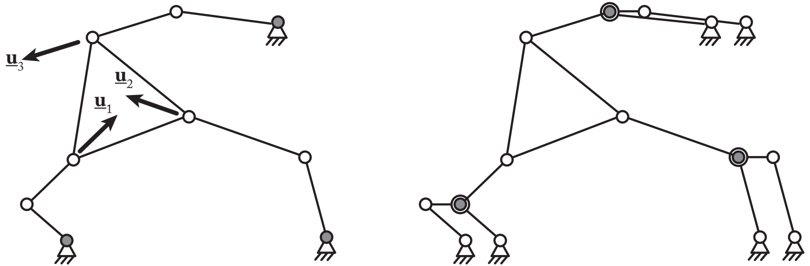

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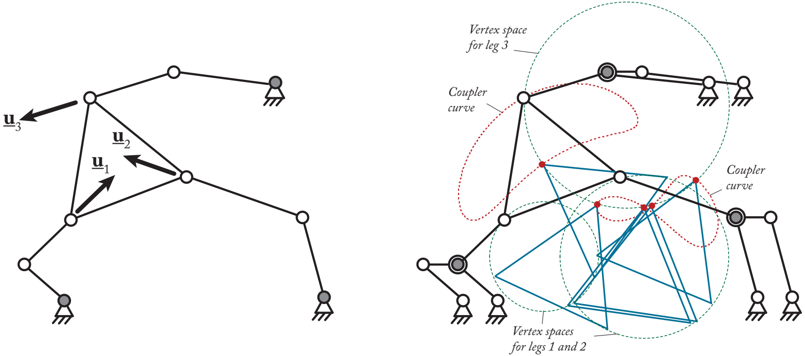
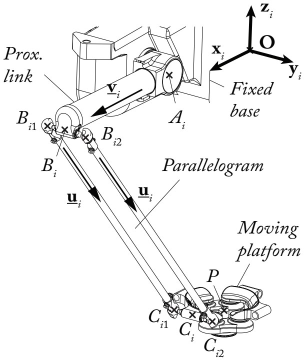


Generalization of the concept and application to different robot classes

Spatial robots

Example of the Adept Quattro



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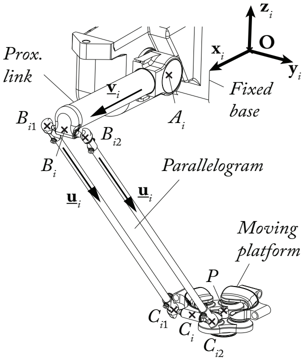

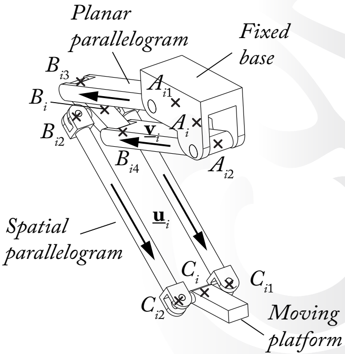

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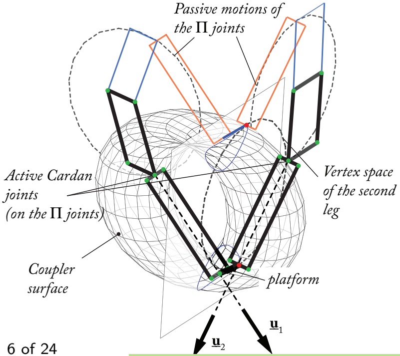

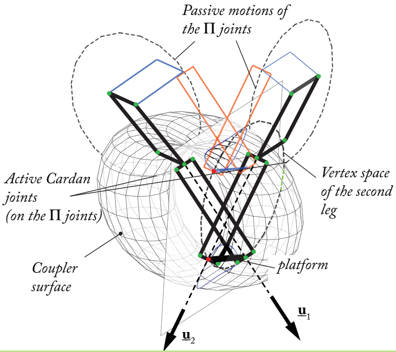

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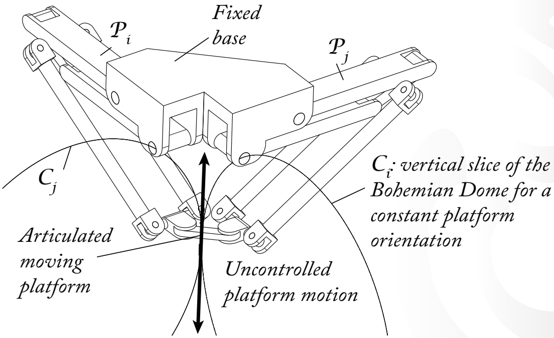
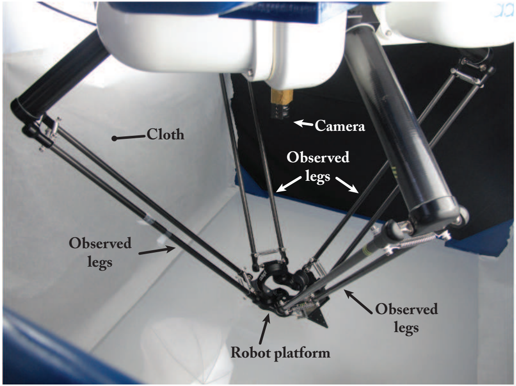


Generalization of the concept and application to different robot classes

Experimental validation



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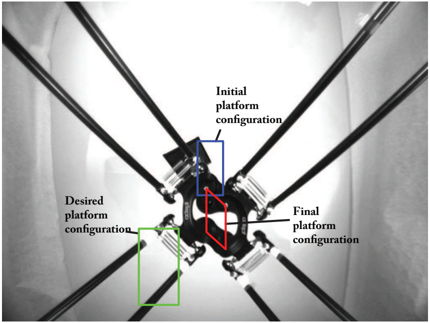
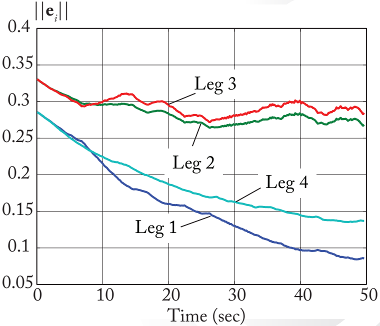




Use of the concept of hidden robot for the controllability analysis

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

Cl 1: Robots which are not controllable

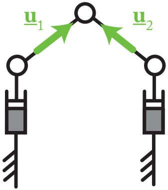
Cl 2: Robots which are partially controllable in their whole workspace

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

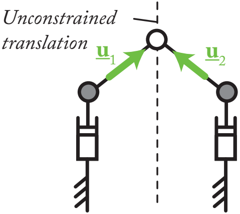
Cl 4: Robots which becomes controllable by using additional measurements

Use of the concept of hidden robot for the controllability analysis

Class 1: Robots which are not controllable



A *PRRRP* robot



Hidden robot:
a *PRRRP* robot

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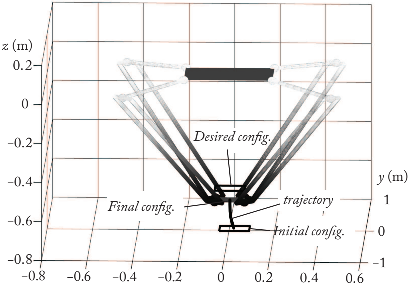
Class 2: Robots which are partially controllable in their whole workspace

⇒ because singularities of the hidden robot **always** divide the workspace into several aspects (unconnected areas)



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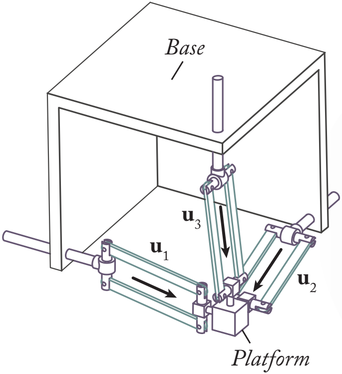
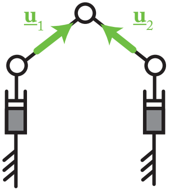
Class 3: Robots which are fully controllable in their whole workspace



Use of the concept of hidden robot for the controllability analysis

Class 4: Robots which becomes controllable by using additional measurements



A *PRRRP* robot

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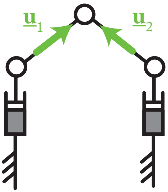
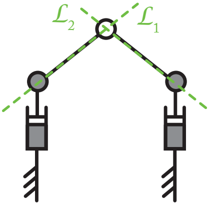


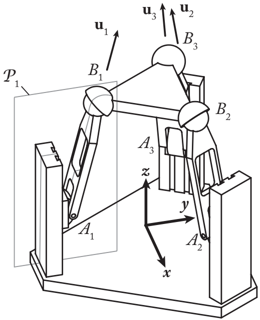
A *P*RRR*P* robot



Hidden robot:
a *P*R*R*R*P* robot

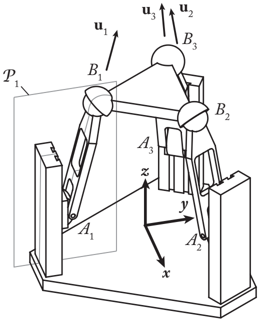
Case study

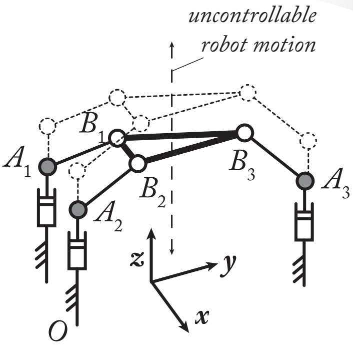
A 3–*PRS* robot



Case study

A 3–$\underline{P}RS$ robot





Case study

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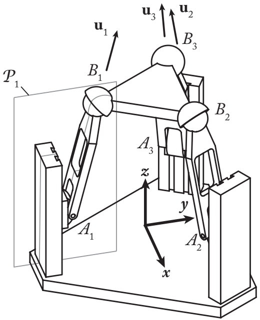

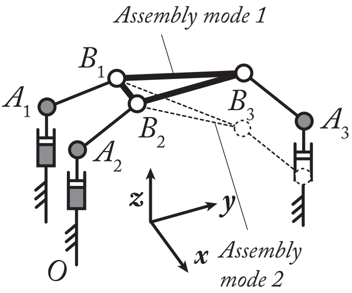

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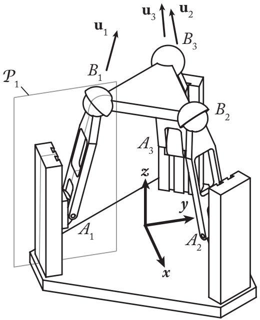
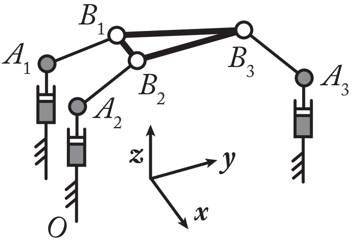
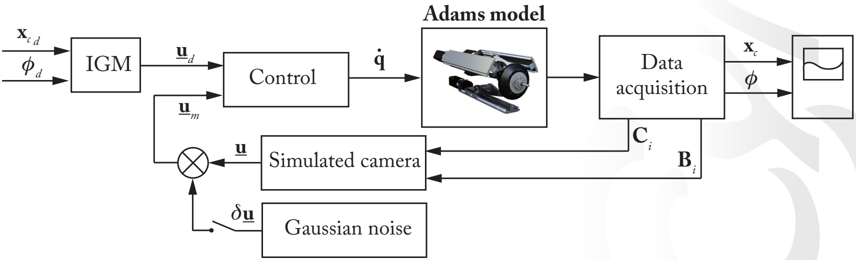




Case study

A 3–*<u>P</u>RS* robot

Results confirmed through simulations



Use of the concept of hidden robot for control-based design

Basic idea:

To modify the design of robots in order to improve their performance when controlled by using leg-based visual servoing

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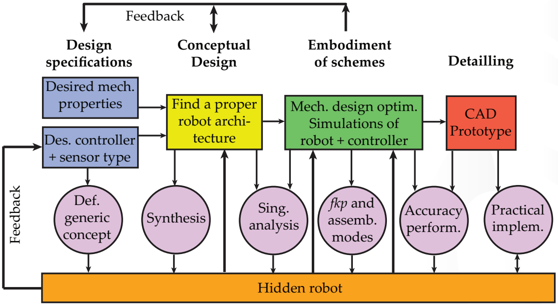
Why?

- For robot of Class 2: in order to allow the full controllability in the whole workspace
- Even if the robot is fully controllable, avoid performance issues (accuracy) near singularities of hidden robot

Use of the concept of hidden robot for control-based design

Modification of the French design process



Use of the concept of hidden robot for control-based design

Preliminary results: Optimization of a Five-bar mechanism

Objective: minimize the robot footprint

Constraints:

- no singularities of the real robot
- velocity and effort transmission performance
- accuracy performance < 0.5 mm

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Accuracy performance depends on the controller

- on the encoder accuracy in encoder-based control
- on the camera accuracy in leg-based visual servoing

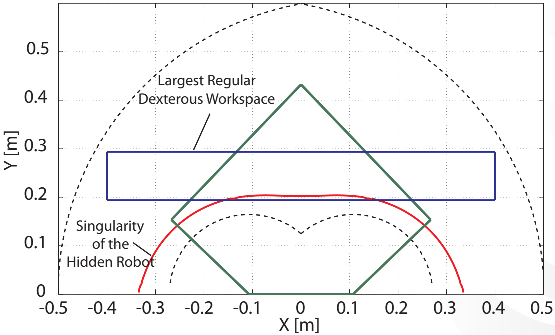
Use of the concept of hidden robot for control-based design

Table: Optimal design parameters and value of the objective function

Encoder-based controller		Direction-based controller (${}^{c}\underline{\mathbf{u}}_i$)	
ℓ_0 [m]	0.1071	ℓ_0 [m]	0.1092
ℓ_1 [m]	0.2219	ℓ_1 [m]	0.2291
ℓ_2 [m]	0.3863	ℓ_2 [m]	0.3750
y_c [m]	N/A	y_c [m]	0.4340
z_c [m]	N/A	z_c [m]	0.5908
A [m^2]	0.1144	A [m^2]	0.1156

Use of the concept of hidden robot for control-based design

If we apply a direction-based controller on the robot optimized for encoder-based controller (Adams/Matlab co-simulation)



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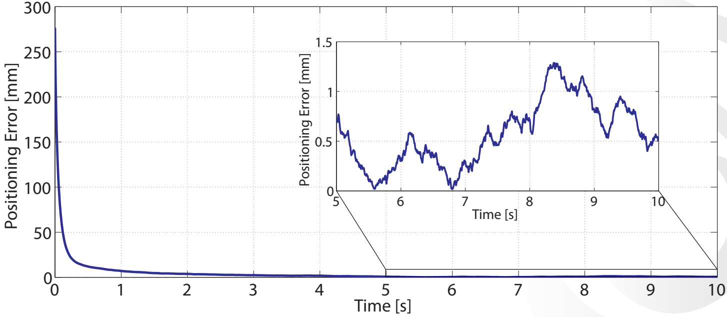

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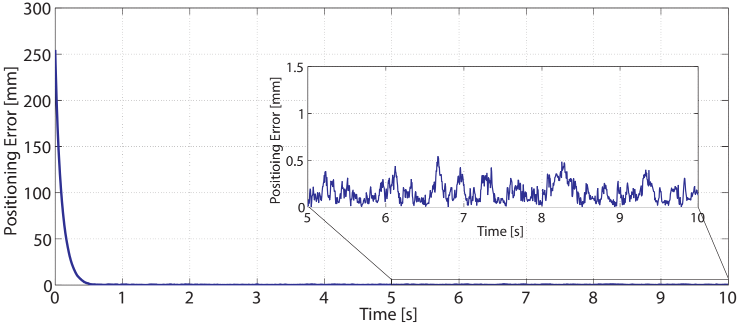
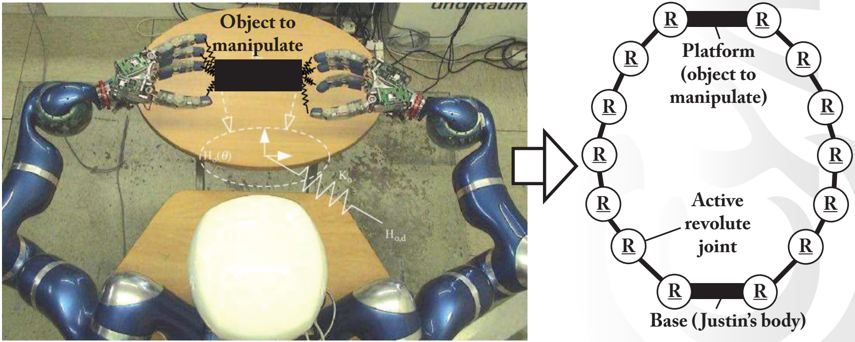
If we apply a direction-based controller on the robot optimized for leg-direction-based controller



Use of the concept of hidden robot for the analysis of other classes of servoing

Visual servoing of multi-arm robots



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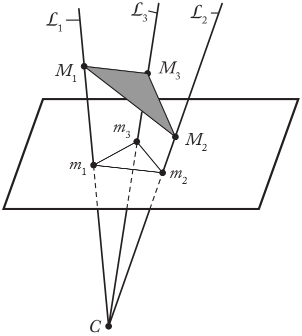
Visual servoing of geometric primitives



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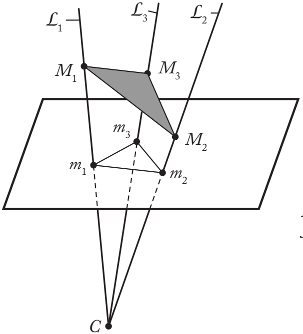

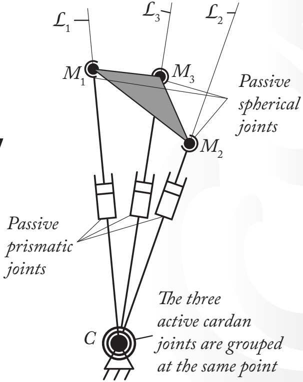

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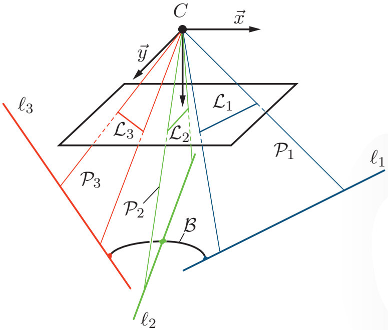

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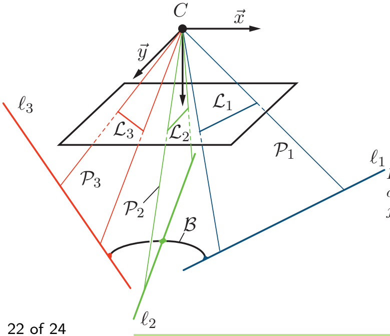

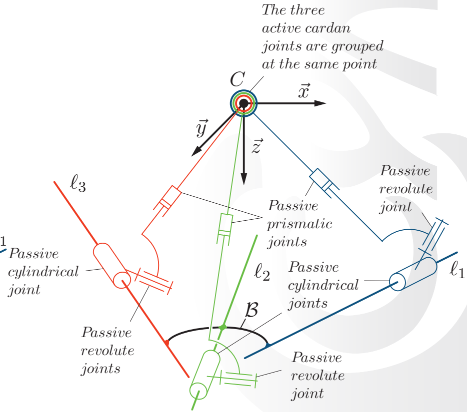

The hidden robot concept

Is a tool coming from the mechanical engineering community for solving problems of the visual servoing community

Allowed first to understand, for leg-based controller of pkm, following issues:

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Allowed first to understand, for leg-based controller of pkm, following issues:

- 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
- singularities of the controller model

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- different pkm families,
- for certifying the controllability analysis

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Is currently extended to

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Was generalized and applied to

- different pkm families,
- for certifying the controllability analysis

Is currently extended to

- for control-based design of robots
- for controllability analysis of more generic controllers (not dedicated to parallel robots)