First workshop for young researchers on Human-friendly robotics

Modelling and control for Human-Robot Interaction

Agostino DE SANTIS
PRISMA Lab
Università degli Studi di Napoli Federico II
agodesa@unina.it
http://wpage.unina.it/agodesa
www.phiends.eu

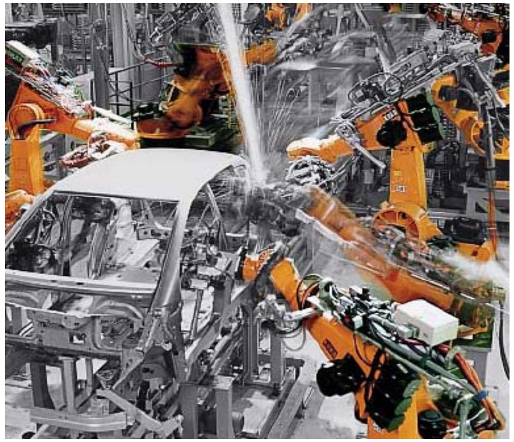
Napoli, 24 October 2008

outline

- safer robots: the framework of PHRIENDS
- modelling and control
  - skeleton algorithm
- experiments
  - service robotics
  - industrial robotics
- Virtual Reality tools
- conclusion

robot safety and PHRIENDS

- Human–Robot Interaction: cHRI and pHRI
- human-centered robotics: optimality criteria
  - safety and dependability
- strategies for safety
  - intrinsic
  - by means of control
- collision tactics
  - before collisions
  - after collisions

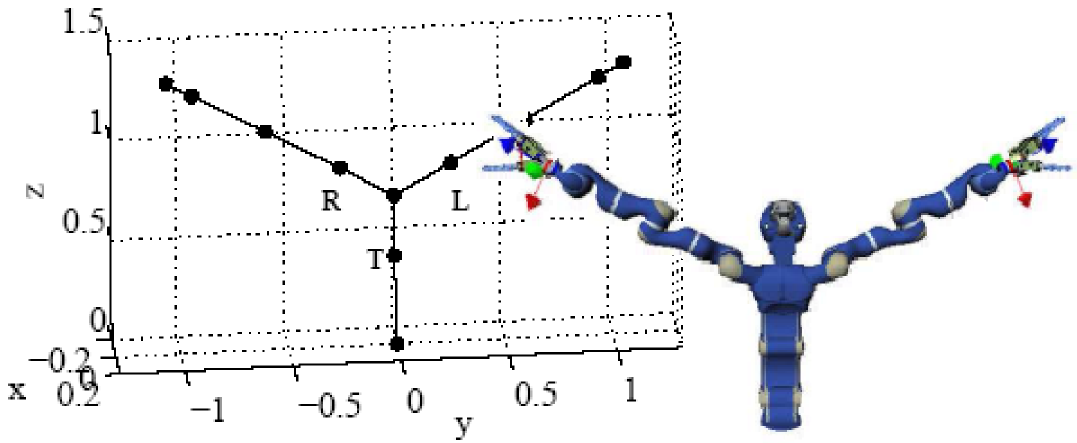


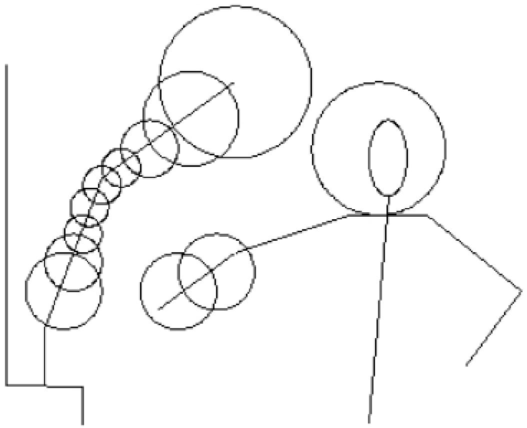
issues for safe reactive control in HRI

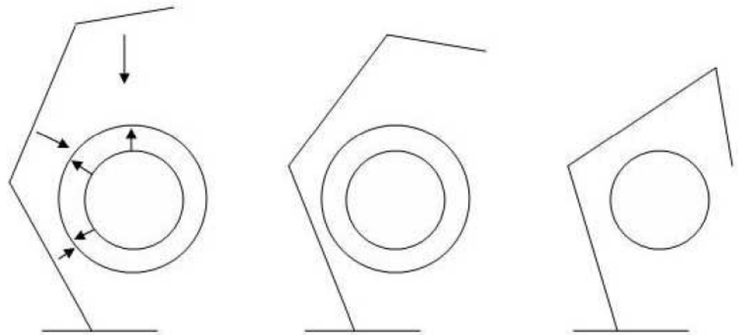
- environment modelling for simple geometric computation
- multiple-point control approach for considering both multiple inputs and multiple outputs of the robot
- arbitrary selection of the control points on the robot
- reactive real-time control for safety
- integration with deliberative tasks and other safety tactics

skeleton-based modelling

- human, robot and environment



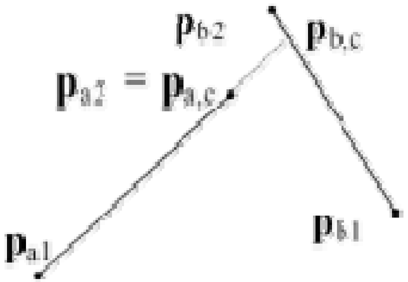


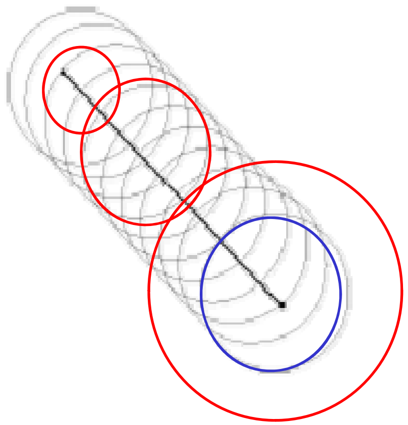


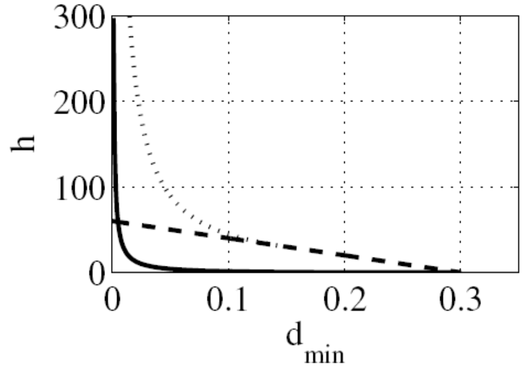
Agostino De Santis
Napoli • 24 Oct 2008

skeleton algorithm/1

- simple case:segments (and wrapping volumes)







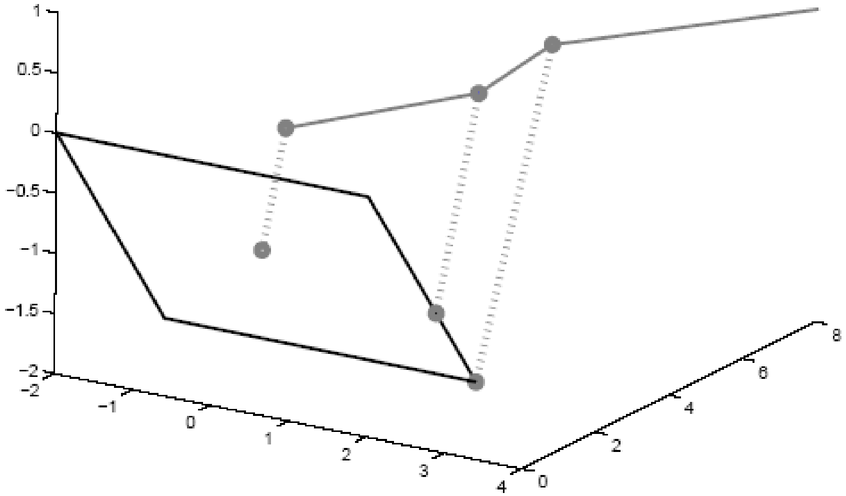
- distances between segments

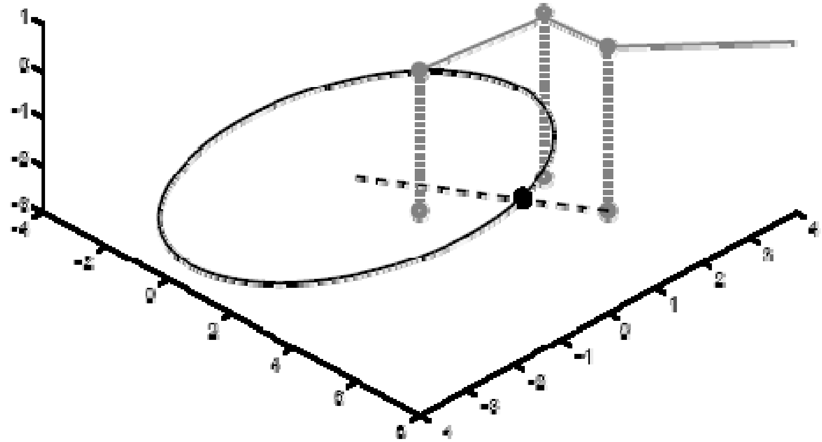
$$p_a = p_{a1} + t_a u_a \qquad u_a = \frac{1}{||p_{a2} - p_{a1}||}(p_{a2} - p_{a1}) \qquad t_{a,c} = \frac{(p_{b1} - p_{a1})^T (u_a - k u_b)}{(1 - k^2)}$$

$$p_b = p_{b1} + t_b u_b \qquad u_b = \frac{1}{||p_{b2} - p_{b1}||}(p_{b2} - p_{b1}) \qquad t_{b,c} = \frac{t_{a,c} - u_a^T (p_{b1} - p_{a1})}{k}$$

skeleton algorithm/2

- modelling the environment





- torque commands

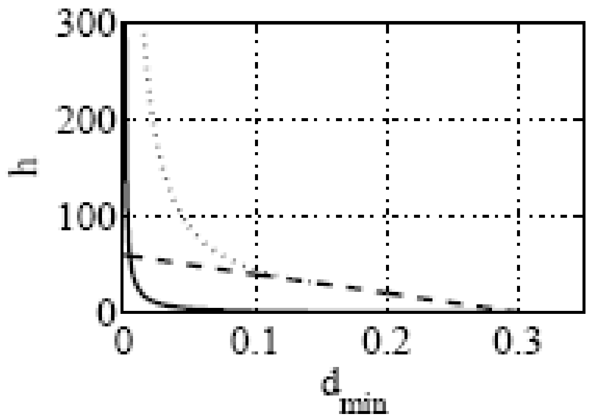
$$\boldsymbol{\tau}_c^T = -\frac{\partial U_c}{\partial \boldsymbol{q}} = -\frac{\partial U_c}{\partial d_{min}} \frac{\partial d_{min}}{\partial \boldsymbol{p}_c} \frac{\partial \boldsymbol{p}_c}{\partial \boldsymbol{p}_i} \frac{\partial \boldsymbol{p}_i}{\partial \boldsymbol{q}}$$

- on-line trajectory planning for control points
  - intensity of force/velocity proportional to distance between possibly colliding points

$$U_c(d_{\min}) = -\int_{d_{\min}}^{\infty} h(\delta, d_0, d_{\text{start}})d\delta$$

$$\boldsymbol{f}_{a,c} = \frac{h(d_{\min}, d_0, d_{\text{start}})}{d_{\min}}(\boldsymbol{p}_{a,c} - \boldsymbol{p}_{b,c})$$

$$\boldsymbol{f}_{b,c} = \frac{h(d_{\min}, d_0, d_{\text{start}})}{d_{\min}}(\boldsymbol{p}_{b,c} - \boldsymbol{p}_{a,c}) = -\boldsymbol{f}_{a,c}$$



- adjustable parameters
  - repelling force (velocity), damping, limit distances

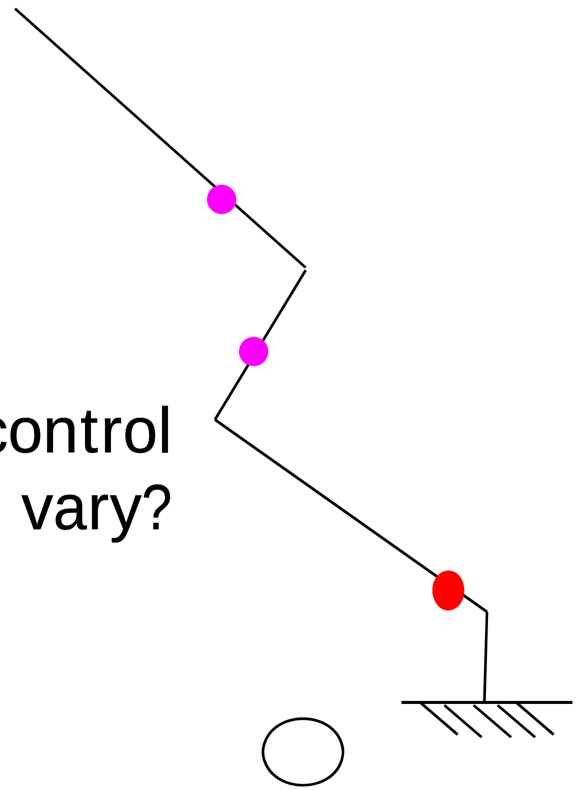
Agostino De Santis

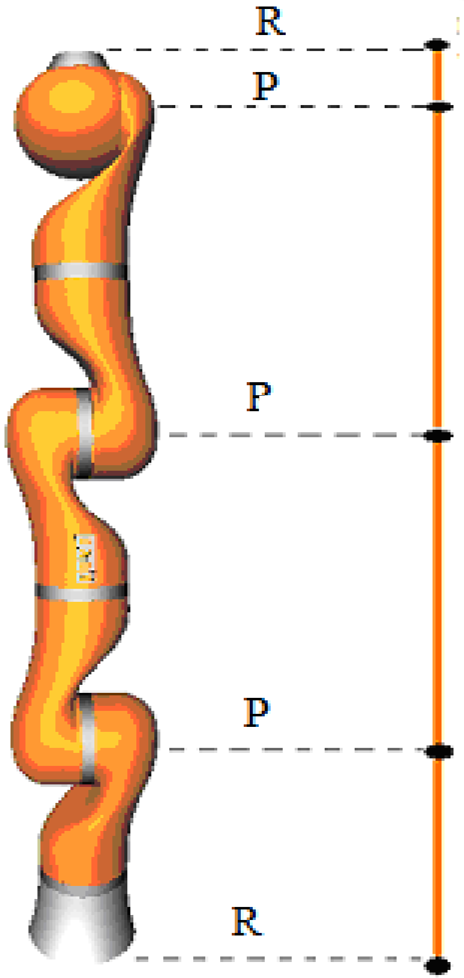
additional aspects

- torque vs velocity interface
- an arbitrary control point on an arbitrary link: a Jacobian per link (rigid body)
  - still, motion of the control point on the link can occur
- the number of control points that can be managed in real-time is limited
- case of parallel segments
- implementation in velocity control and CLIK
- modular way for considering a moving control point: symbolic direct kinematics and Jacobian

single moving control point

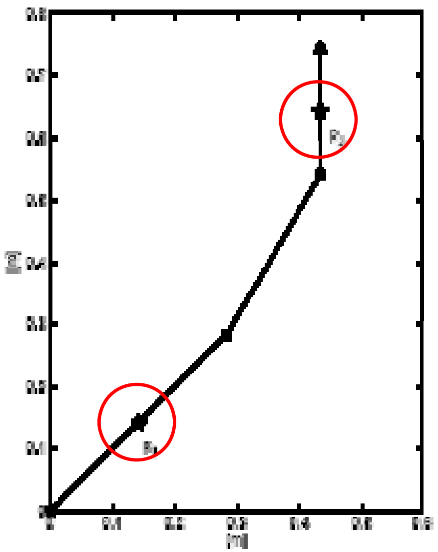
- problem: discontinuities
- interpolation
- how does the control point's position vary?

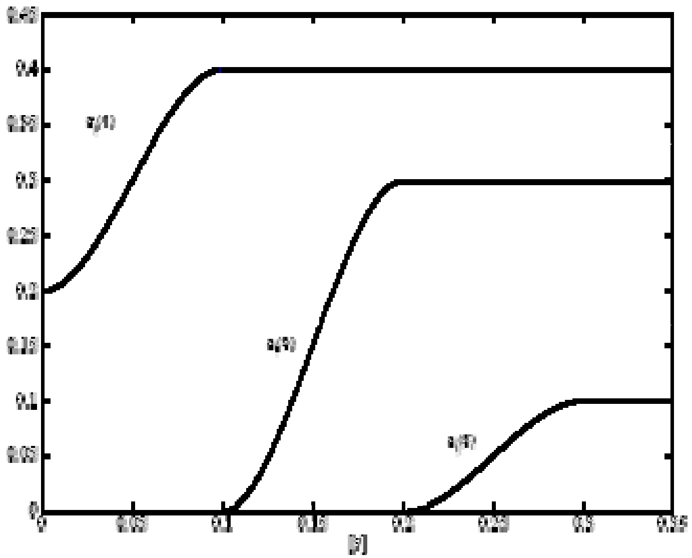




Denavit-Hartenberg-based modelling

- direct kinematics for a generic control point
  - a_i, d_i, α_i, θ_i → p_i=K(D&H) for a certain set of DH-values
  - generic symbolic expression for a control point, where proper DH values have to be considered
- example of change of control point with continuity





Agostino De Santis
Napoli• 24 Oct 2008

- modification to differential kinematics

$$\dot{\boldsymbol{p}}_i = \frac{\mathbf{dK}}{\mathbf{dt}} = \frac{\partial \boldsymbol{K}}{\partial \boldsymbol{\theta}_i}\frac{\partial \boldsymbol{\theta}_i}{\partial t} + \frac{\partial \boldsymbol{K}}{\partial \boldsymbol{a}_i}\frac{\partial \boldsymbol{\alpha}_i}{\partial t} + \frac{\partial \boldsymbol{K}}{\partial \boldsymbol{d}_i}\frac{\partial \boldsymbol{d}_i}{\partial t} =$$

$$= \boldsymbol{J}_{\theta,i}(\boldsymbol{\theta}_i, \boldsymbol{a}_i, \boldsymbol{d}_i)\dot{\boldsymbol{\theta}}_i + \boldsymbol{J}_{a,i}(\boldsymbol{\theta}_i, \boldsymbol{a}_i, \boldsymbol{d}_i)\dot{\boldsymbol{a}}_i + \boldsymbol{J}_{d,i}(\boldsymbol{\theta}_i, \boldsymbol{a}_i, \boldsymbol{d}_i)\dot{\boldsymbol{d}}_i$$

$$\Downarrow$$

$$\dot{\boldsymbol{\theta}}_i = \boldsymbol{J}^{\dagger}_{\theta,W,\mathbf{i}}(\dot{\boldsymbol{p}}_i - \boldsymbol{J}_{d,i}(\boldsymbol{\theta}_i, \boldsymbol{a}_i, \boldsymbol{d}_i)\dot{\boldsymbol{d}}_i)$$

experimental set-up

- DLR Justin
  - 17-DOF
  - 2 DLR LWR-III + torso
  - 26 DOFs hands
  - vision
  - DLR aRD
  - C + MATLAB®
- COMAU Smart 3/S
  - 6-DOF
  - C3G “open” controller
  - RePLICS

experiments with the DLR Justin humanoid

- collision avoidance

experiments @ DLR

- adjustable parameters: damping

application to an industrial robotic cell

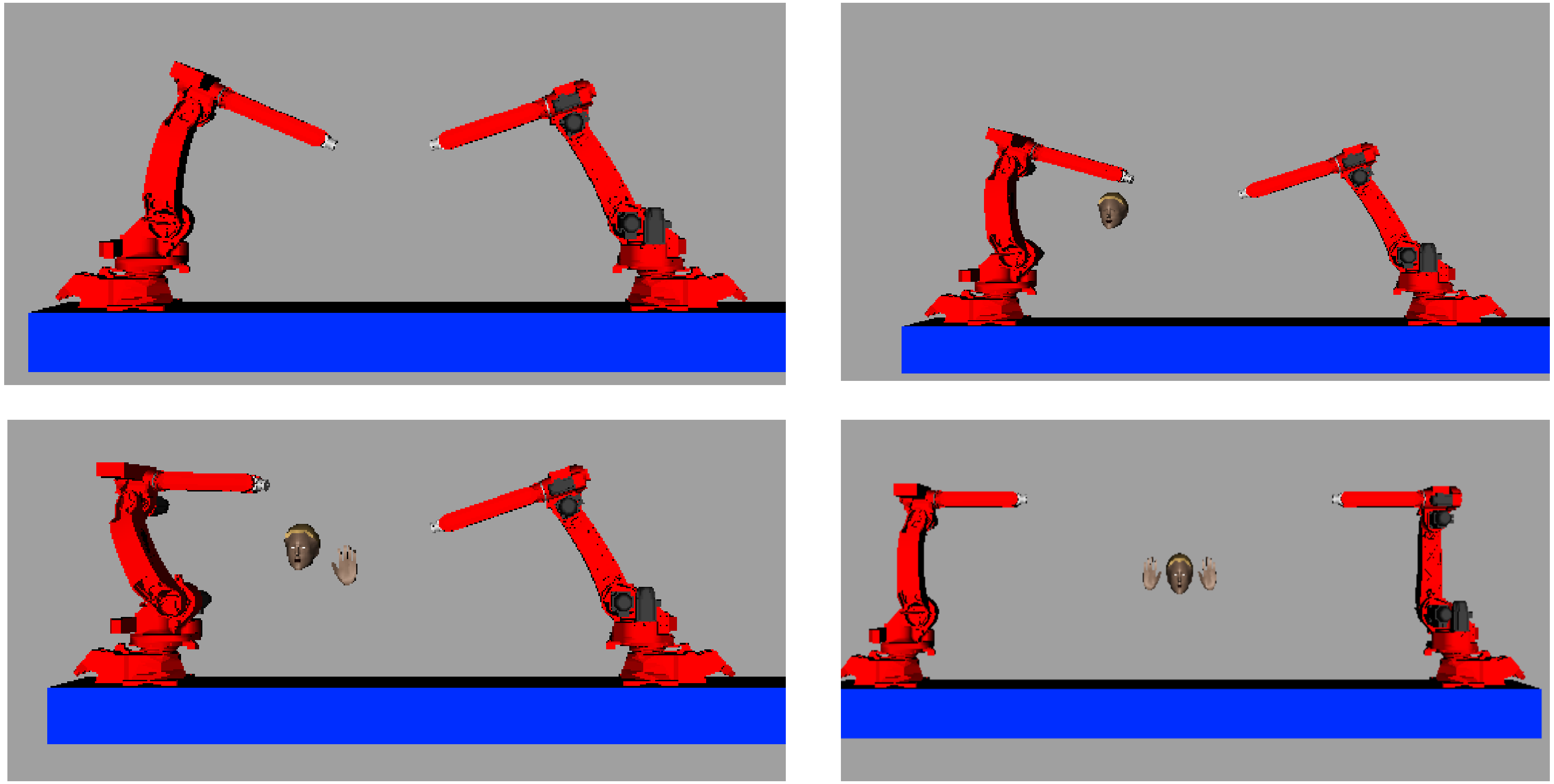
- face detection, attractive and repulsive motions

rehabilitation robotics scenario in VR

- features: adding errors without risk of harm, evaluating comfort (and *perceived* dependability)

Virtual Reality tools

- Preliminary test of algorithms with models of new equipment



- safety and dependability in human-friendly robotics
- skeleton-based modelling
- real-time properties
- reactive control: torque and velocity interface
- use of Virtual Reality tools

- current research: robustness and dependability of the approach, more complex models for reactive control

Thank you very much for your kind attention ☺

Modelling and control for Human-Robot Interaction

Agostino DE SANTIS
PRISMA Lab
Università degli Studi di Napoli Federico II
agodesa@unina.it
http://wpage.unina.it/agodesa
www.phiends.eu

Napoli, 24 October 2008