Intervention robots in constrained environments

CIGRE 2012

Study Committee B2
Working Group 52

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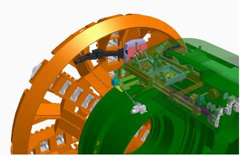
Context

From industrial manufacturing Robotics towards field and intervention Robotics in complex industrial environments ...



Field robots in complex industrial environments?

- Construction, maintenance and dismantling of complex industrial products or sites
- Domains : Construction and public works, production and transportation of energy, naval construction and aeronautics...

Characteristics of these new fields of application of Robotics

- Very constrained and partially structured/known environments: geometrically, mechanically, chemically, electrically...
- Various missions in close interaction with humans: load bearing, gravity compensation, force amplification, assistance to precise manipulation, repetitive mechanical tasks...
- Multiple modes: autonomous, collaborative

Problem !

Absence of design methodologies and of validation strategies dedicated to these new contexts of application of Robotics

Objectives

Development of methods and tools for the design and the validation of robots and their control laws dedicated to interventions in complex environments

1. Intrinsically safe control of intervention robots evolving under constraints and in interaction with human operators
2. {Constraints and Tasks}-based design of physical architecture/morphology of intervention robots
3. Validation through realistic physics simulation: quantitative evaluation of the operational performance induced by the physical and control architecture of the robot, quantitative evaluation of the safety of robot interactions with its environment

Case of application: maintenance of power lines

- Provide a robotic assistance for the realisation of maintenance operations
- In a semi-autonomous way or in teleoperation in substations: visual inspections, measurements, interventions...
- **In pylons...in interaction with human operators...for complex missions**

$\hookrightarrow$ **Gain of autonomy and safety for the human operators**

Control: recent results

- Design of a control law for the tracking of (multiple) operational objectives while avoiding collisions in a highly constrained environment

Constraint Compliant Control

- 3-level control law:
  - High priority objectives: Passive avoidance
  - Secondary objectives: Operational objectives tracking
  - Low priority objectives: Active avoidance

movie1 movie2 movie3

$$\dot{q} = J_c^+ 0 + (J_O P_{J_c})^+ \dot{X}_{des,0} + (J_{\bar{c}} P_{\begin{bmatrix} J_c \\ J_O \end{bmatrix}})^+ (\dot{X}_{des_{\bar{c}}} - J_{\bar{c}} (J_O P_{J_c})^+ \dot{X}_{des,0})$$

Control : ongoing work

Existing limits

- Dynamics is not considered and robot is velocity controlled
- Static obstacles
- Constraints and specificities related to parallel comanipulation are not considered
- Perception and knowledge of the environment is assumed to be perfect

Antoine Seeleuthner, PhD thesis (2011–)

- "Multi-objective control of robotic manipulators under constraints and in collaboration with human operators"

Related publication

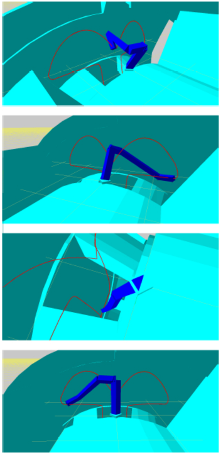
- S. Rubrecht, V. Padois, P. Bidaud, M. de Broissia, and M. Da Silva Simoes : *Motion safety and constraints compatibility for multibody robots.*. Autonomous Robots, Springer Netherlands, publisher. Vol 32 No 3 Pages 333–349, 2012.

Design: recent results

Formalization of the design problem as a constrained optimization problem

- Formal description of robotic systems (body / link)
- Complex multi-objective problem of ↗ dimensions
- Large solution space

↪ **MO evolutionary algorithms**



Existing software developments

- NSGA2 in the Sferes framework
- Fitness function evaluation through simulations

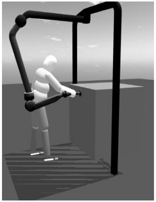
Design: ongoing work

Existing limits

- Technical: software integration
- Scientific: optimization objectives related to comanipulation are not accounted for

Pauline Maurice, PhD thesis (2011–)

- Collaboration with CEA-LIST
- "Automatic design of morphologies and operational procedures for robotic assistants in the industry".

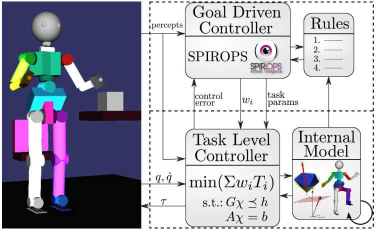


Related publications

- S. Doncieux, J.-B. Mouret, N. Bredèche, and V. Padois : *Evolutionary robotics : Exploring new horizons.* In *New Horizons in Evolutionary Robotics, vol. 341 of Studies in Computational Intelligence*, Springer, 2011.
- S. Rubrecht, V. Padois and P. Bidaud : *Evolutionary design of a robotic manipulator for a highly constrained environment.* In *Doncieux, S., Bredèche, N., and Mouret, J.-B., editors, New Horizons in Evolutionary Robotics : extended contributions from the EvoDeRob workshop, volume 341 of Studies in Computational Intelligence*, Springer, 2011.
- P. Maurice, Y. Measson, V. Padois and P. Bidaud : *Assessment of Physical Exposure to Musculoskeletal Risks in Collaborative Robotics Using Dynamic Simulation*. To appear in *proceedings of the 19th CISM-IFToMM Symposium on Robot Design, Dynamics, and Control (Romansy)*, 2012.

Realistic Simulation : recent results

Automatic Synthesis of complex activities for avatars



Tasks $(T_i(\chi))$

$$\chi = [\ddot{\boldsymbol{q}}, \boldsymbol{\tau}, \boldsymbol{w}_c]^T$$
$$T = \|E\chi + \boldsymbol{f}\| \quad \left(T_{acc} = \left\| J\ddot{\boldsymbol{q}} + \dot{J}\dot{\boldsymbol{q}} - \dot{\boldsymbol{t}}^{des} \right\|\right)$$

Constraints $(A\chi \leq \boldsymbol{b})$

$$M\ddot{\boldsymbol{q}} + N = \boldsymbol{g} + J_c^t \boldsymbol{w}_c + S\boldsymbol{\tau}$$
$$\boldsymbol{\tau}_{min} \leq \boldsymbol{\tau} \leq \boldsymbol{\tau}_{max}$$
...

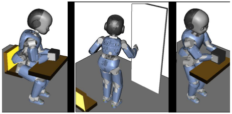
Realistic Simulation: ongoing work

Existing limits

- Technical: Software development in the XDE@CEA framework
- Scientific: Decision making for complex activity generation in humanoid robotics still a challenge

Aurélien Ibanez, PhD thesis (2011–)

- "Unified preview control for humanoid postural stability and upper-limb interaction adaptation"



Related publications

- J. Salini, V. Padois and P. Bidaud : *Synthesis of complex humanoid whole-body behavior: A focus on sequencing and tasks transitions*. In *Proceedings of the 2011 IEEE International Conference on Robotics and Automation*, pp. 1283-1290. Shanghai, China, 2011.
- J. Salini, V. Padois, P. Bidaud and A. Buendia : *A Goal driven perspective to generate humanoid motion synthesis*. In *Proceedings of the 14th CLAWAR International Conference*. Paris, France, 2011.
- A. Ibanez, P. Bidaud and V. Padois : *Safe Biped Balance and Manipulation through Disturbance Preview*. To appear in IROS 2012.

Concluding remarks

- The design of such robots is a multi-level problem : design, control, validation...
- Comanipulation is a good compromise to provide assistance without losing human expertise
- High voltage power line maintenance is a very good example of application

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