

A VIEW ON ROBOT FORCE CONTROL

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State-of-Art

One of the fundamental requirements for the success of a robot manipulation task is the capability to handle *interaction between manipulator and environment*. The quantity that describes the state of interaction more effectively is the *contact force* at the manipulator's end effector.

Control strategies for a robot manipulator in contact with an environment can be grouped in two categories; those performing open-loop force control and those performing direct closed-loop force control. To the first category belong the *impedance control* schemes that achieve indirect force control by means of closed-loop position control. The most common strategy belonging to the second category is the *hybrid position/force control* where either a position or a force is controlled along each task space direction. Two alternative strategies still in the second category are the *inner-outer position/force control* where an external force control loop is closed around the internal position control loop, and the *parallel force/position control* where both a position and a force are controlled along each task space direction with dominance of the force action above the position one. On the other hand, if a complete geometric description of the environment is available, enhanced performance is obtained with control strategies which make use of *kinesthetic filtering* to separate the directions to control in force from those to control in position.

Research Perspectives

In the framework of the European Robotics NETWORK (ERNET), *force control* has received large attention with 6 participants proposing projects on this research topic (second only to the topic of mobile robots).

- The DEIS at University of Bologna has proposed a project on force/position control in telemanipulation tasks, with specific regard to the presence of time delays, the use of advanced sensorial systems, the design of control schemes based on dynamic compensation, and the experimentation on a set-up based on a six-dof articulated arm equipped with force sensors.

- The DIS at University of Naples has proposed a project on force control, with specific regard to new passivity-based control schemes for motion control and force regulation, and their experimentation on a Comau SMART-3 S industrial robot equipped with an ATI force sensor FT30-100.
- The DEI at Polytechnic of Milan has proposed a project on hybrid control, with specific regard to deburring operations and experimentation on a Comau SMART-3 S industrial robot equipped with an ATI force sensor FT30-100.
- The LAG at INP-Grenoble has proposed a project on adaptive feedforward compensation for force/position control, with specific regard to the case of joint flexibility and experimentation on a 2-dof arm equipped with a real-time dSPACE control architecture and a force sensor.
- The LRP at Université Paris 6 has proposed a project on impedance control for dynamically complex tasks, with specific regard to the experimentation on an industrial manipulator with a moving environment constituted by a second manipulator.
- The Automatic Control Lab at ETH-Zürich has proposed a project on force/compliance control of a mobile manipulator, with specific regard to large position uncertainties, nonholonomic motion constraints and dynamic coupling between manipulation and motion.

All the listed research projects look very interesting. Significant results have already been achieved and it is wished that the research staff exchanges between the above participants planned during 1995 will contribute further developments in this area.

Other research issues in the context of force control which are believed to be worthy of investigation are: *modelling of dynamic environments*, *modelling of impact phenomena*, *6-dof task control* (position and orientation, force and moment), *stability of control schemes during transition from non-contact to contact*, and *force/position control of robot manipulators with flexible joints and/or links*.