Modelling and Control for Human–Robot Interaction

Agostino De Santis

I. Introduction

The presentation introduced by this extended abstract is based on recent work on modelling and control of robots for applications where the presence of humans in the robot's workspace is explicitly considered [1] [2]. In such situations, fast reactive behaviours are required, together with proper tactics for safety, both intrinsic and by means of control.

In the latest years, great interest has been shown towards a possible future generation of robots, for service applications or cooperative work, that are expected to interact with people more directly than today. While there is a focus on Human-Robot Interaction (HRI) at the cognitive level (cognitive HRI or cHRI), robots are distinct from computers or other machines. Basically, they can generate forces and have a mechanical, possibly heavy, body: hence, the most revolutionary and challenging feature of the next generation of robots will be physical Human-Robot Interaction (pHRI) [3].

The requirements for robots met in conventional industrial applications are fast motions and absolute accuracy, without external sensing, provided that the operational environments are perfectly known. The most important change of perspective is related to the optimality criteria for robots designed to cooperate with humans: safety and dependability are the keys to their successful introduction into human environments. Physical safety has to be complemented by the mental safety, i.e., by the awareness of robot motion, avoiding scaring postures and abrupt movements. The on-going European project Physical Human-Robot Interaction: Dependability and Safety (PHRIENDS) [4] has the mission of developing key components of the next generation of robots, designed to share the environment and to physically interact with people, meeting safety standards while delivering useful performance: this poses new challenges to the design of all components of the robot, including mechanics, control, planning algorithms and supervision systems, sensing. Different approaches to safety are addressed, considering compliance of the robot in case of contact, fast monitoring of the scene, precise collision checks with emergency stops. It is therefore possible to consider three kind of strategies: tools aimed at intrinsic safety, strategies for preventing collisions, solutions activated in the event of a crash. The second approach in the proposed list will be addressed more in depth.

This work was supported by the PHRIENDS Specific Targeted Research Project, funded under the 6th Framework Programme of the European Community under Contract IST-045359. The author is solely responsible for its content. It does not represent the opinion of the European Community and the Community is not responsible for any use that might be made of the information contained therein.

A. De Santis is with PRISMA Lab, DIS, Università di Napoli Federico II, Italy, agodesa@unina.it

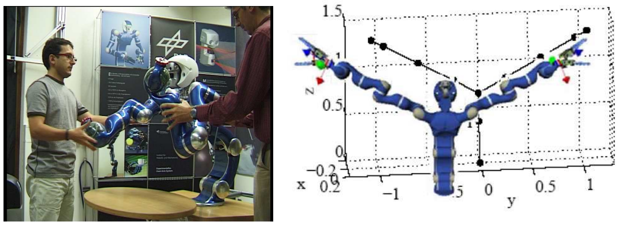

Fig. 1. Real-time interaction with a humanoid manipulator and adopted skeletal model for the robot.

II. Modelling and reactive planning/control

A first idea is a fast modelling of the interacting people and robot, providing a manipulator's and world's model for fast deliberative/ reactive motion, with arbitrary control points on the robot and the possibility of combining different trajectories for the fulfilment of different tasks, to be specified at a higher level.

The considered issues are as follows:

- 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.

These point have been addressed with the so-called skeleton approach, first studied for collision avoidance. The problem of analyzing the whole volume of the parts of a manipulator is simplified by considering a skeleton of the structure (see Fig. 1), and proper volumes surrounding this skeleton. The underlying idea is that a solid of revolution can express the volume around the spine of a link: this can be shaped by properly using repelling functions from every point of the link, which then create a safe volume around the point. In other words, if it possible to control every point on the skeleton, repulsion forces coming from such points will reflect the shape of the mechanical structure around the skeleton.

If people and robot are modelled as skeletons, only distance evaluations between couples of segments are needed. For each segment in which the structure is decomposed, the distance to all the other segments is therefore calculated with analytical formulas, allowing a real-time computation of the closest points on each segment of the robot, namely, the control points. Spheres centered at the control points can be considered as protective volumes, where repulsion has to start. Since the closest point can vary between the two ends of the segment, on the assumption of a fixed radius, the resulting protective volume will be a cylinder with two half spheres at both ends. With a variable radius, different shapes can be obtained. At the same time, also attractive behaviours and arbitrary motions for a generic control point can be generated using the same tools.

Since the control points can be located everywhere along the segments of the skeleton, the direct kinematics and the Jacobian computation can be carried out in a parametric way for a generic point on each segment by simply replacing the link length in the homogeneous transformation relating two subsequent coordinate frames with the distance of the control point from the origin of the previous frame.

When taking also the environment into account, a more complete model is necessary, which generalises the skeleton approach: objects in the environment can be delimited by volumes which, in turn, are to be expressed as points, lines, planes. The complexity of such world modelling is affected by the possibility of exploiting heuristics for reducing computation and checks.

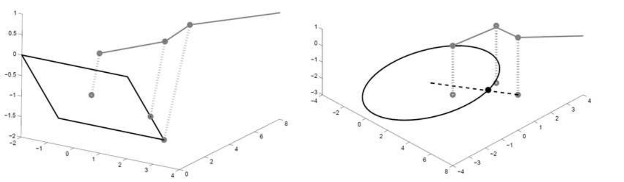

Fig. 2. The distances from segments to a rectangular or circular region are computed as a straightforward extension with respect to distances between segments

For the purpose of generating continuous reference trajectories, mutual distance computation between the geometric quantities in the world model has to be performed fast. The distance computation for couples of segments and point-to-segment distances are then complemented with analytical formulas for the distance from planes. This is a straightforward generalisation which can be easily obtained considering the distances between lines and planes.

Potential fields or deliberative trajectories can be used in order to generate the forces or the velocities which will produce the desired motions. It is worth noticing that both a torque-based [1] and a velocity-based [5] control have been proposed, based on the introduced tools.

Adjustable parameters in the potential field shaping also result in a more precise motion. The ways for obtaining complex repelling shapes for objects in pHRI scenarios, by modifying parameters in the function which describes the repulsion force, include modifications of the amplitude of such function (creating more or less stiff virtual elastic walls) and changes in limit distances, which identify the source of attracting or repelling effects with respect to the spine of the considered skeletal models. Real-time specifications are considered: due to the used analytical approach, the computation is really fast, and additional safety tactics can be implemented in the sampling time of the controller.

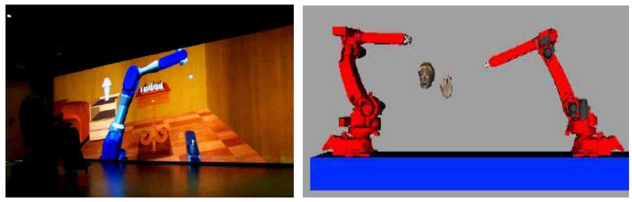

Fig. 3. Immersive VR applications and a virtual robotic cell

III. Experiments

Experiments have been developed both with service and industrial robots [2], and will be discussed during the presentation for proving robustness and effectiveness of the proposed tools. In particular, experimental sessions at the DLR with the humanoid manipulator Justin [6] show a robust self-collision avoidance for the robot, implemented with the skeleton algorithm, and extended also to the avoidance of external objects.

In the experiments performed in the PRISMA Lab, University of Napoli Federico II, a face detection system has been also used for finding and tracking a human interacting with an industrial robot.

Since control of pHRI tasks has to focus on the user as well as on the robot, simulations in Virtual Reality (see Fig. 3) have been also considered, since they are relevant for the evaluation of perceived safety. For such purpose, algorithms have been also tested in an immersive Virtual Reality environment, with focus on a rehabilitation robotics scenario [7].

Finally, a virtual model of the dual-arm robotic cell recently available in the PRISMA Lab has been developed for preliminary simulations, in view of future implementation of the proposed algorithms on the novel set-up.

References

[1] A. De Santis, A. Albu-Schäffer, C. Ott, B. Siciliano, G. Hirzinger, "The skeleton algorithm for self-collision avoidance of a humanoid manipulators", *2007 IEEE/ASME International Conference on Advanced Intelligent Mechatronics* , Zürich, CH, 2007.

[2] A. De Santis, *Modelling and Control for Human–Robot Interaction, Research Doctorate Thesis*, Università degli Studi di Napoli Federico II, Italy, 2007.

[3] A. De Santis, B. Siciliano, A. De Luca, A. Bicchi, "An atlas of physical Human–Robot Interaction", *Mechanism and Machine Theory*, Elsevier, vol. 43, pp. 253-270, 2008.

[4] PHRIENDS Research Project Home Page, *http://www.phriends.eu*.

[5] A. De Santis, B. Siciliano, "Inverse kinematics of robot manipulators with multiple moving control points", *11th International Symposium on Advances in Robot Kinematics*, Batz-sur-Mer, F, 2008.

[6] C. Ott, O. Eiberger, W. Friedl, B. Bäuml, U. Hillenbrand, C. Borst, A. Albu-Schäffer, B. Brunner, H. Hirschmüller, S. Kiehlöfer, R. Konietschke, M. Suppa, T. Wimböck, F. Zacharias, G. Hirzinger, "A humanoid two-arm system for dexterous manipulation", *2006 IEEE International Conference on Humanoid Robots*, Genova, I, 2006.

[7] A. De Santis, G. Di Gironimo, A. Marzano, B. Siciliano, A. Tarallo, "A Virtual-Reality-based evaluation environment for wheelchair-mounted manipulators", *6th Eurographics Italian Chapter Conference*, Salerno, I, 2008.