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Safe Physical Human-Robot Collaboration

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Abstract— **The video illustrates on-going activities at DIAG Sapienza on physical Human-Robot Collaboration (pHRC), based on a control framework imposing robot behaviors that are consistent with safety and coexistence requirements.**

Robotics research looks forward to the possibility of eliminating any distance between humans and robots when desired. Robots that can physically collaborate with humans will combine and enhance the skills of both the robot and the human, with multiple potential applications in industrial robotics (robot co-workers) and service robotics (personal assistants). To this end, robots have to be designed and controlled following new guidelines.

We present a control framework for a safe physical Human-Robot Collaboration (pHRC), based on a stack of nested consistent behaviors for the robot [1].

Safety is the most important feature of a robot that has to work close to human beings. In industrial settings, human safety is preserved using cages or slowing down or stopping motion when human presence is detected. These solutions are clearly inappropriate for pHRC.

Coexistence is the robot capability of sharing the workspace with other entities, most relevant with humans in which case human safety requirements must be consistently guaranteed (i.e., safe coexistence).

Collaboration occurs when the robot performs a complex task with a direct human interaction and coordination. We refer to safe physical collaboration when this activity is consistent with a safe coexistence.

These concepts are illustrated with human-robot interaction experiments with a KUKA Lightweight IV robot and a Microsoft Kinect sensor, available in our Robotics Lab [2]. Safety is guaranteed by a collision avoidance method based on depth sensor information. The peculiarity of our approach is to use directly the depth space [3], instead of working with cloud of points in the Cartesian space. Points of interests on the robot are projected in the depth image where robot-to-obstacle distances are computed in a fast way, taking into account also obstacle occlusions, and thus enabling collision avoidance in real time. Beside the human body, the proposed method is able to avoid collision also with multiple static or moving obstacles.

Except for the robot end-effector, all other robot points of interest will treat obstacles as geometric constraints in the Cartesian space. These constraints are satisfied during robot motion, together with the hard limits imposed in the joint space. Robot kinematic redundancy is exploited to obtain fast and dextrous robot motion and reaction, thanks to our Saturation in the Null Space algorithm [4]–[6]. Smooth and natural robot behavior is obtained, providing a sensation of safety to the user.

A collaboration phase is started by the user with a simple gesture, here a hand waving [7]. The robot moves toward the hand that requested collaboration and reaches contact. At this stage, the human can guide manually the robot or perform further collaborative tasks. Only the designated collaborating hand is allowed to contact the robot end-effector, while all other entities are still considered as obstacles. In this way, safe coexistence is guaranteed. The user requests to end the collaboration by pushing on the robot end-effector.

Other contact areas (beside the end-effector) can be localized on line using the depth sensor. Combining this geometric information with the joint torques due to the contact, as obtained with our residual-based method [1], allows to estimate the exchanged Cartesian contact forces. These can be used for physical collaboration, e.g., letting the robot regulate the contact force with the human (without a force sensor).

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