Dynamical obstacle avoidance in human-robot collaboration

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***Abstract*—The trend toward collaborative robotics portends to a workshop layout where robots and humans share the workspace and collaborate in many operations, in a dynamical and unforeseeable scenario. In addition to dedicated hardware and design principles, collaborative robotics implies specific control strategies to ensure safety. In this sense, collision avoidance control techniques represent a powerful means of improving the safety and flexibility of robots. The paper presents a framework for motion planning and control of manipulators aimed at collision avoidance of static and dynamic obstacles. Algorithms are tested in simulation for a redundant collaborative robot (KUKA LBR iiwa).**

***Index Terms*—collision avoidance, collaborative robotics**

I. Introduction

Collision avoidance control techniques represent a powerful means of improving the safety and flexibility of robots, especially cobots, working in a dynamically varying scenario where obstacles or humans can enter the workspace and move during the operation. A number of papers are available in literature on path planning and obstacle avoidance for mobile robots [1], which is a very common problem. More complex is the case of manipulators, that suffer from the limitations of work spaces and problems of singularity. However, redundant manipulators offer greater dexterity than traditional manipulators, which aids in the development of task-oriented control strategies taking advantage of the additional degrees of freedom [2]. Moreover, redundancy can be exploited also with standard manipulators (6 DOFs) if some of the degrees of freedom of the end-effector, e.g. the orientation angles, can be kept free during motion.

Thus, an overall control strategy for a robot operating in a dynamic environment should be based on:

- an off-line path planning algorithm, able to avoid collisions with obstacles inside the workspace;
- a strategy for the avoidance of singular configurations of the manipulator;
- an on-line collision avoidance control, able to compensate for possible motions of the obstacles, or obstacles entering the workspace of the robot while it is already moving;
- a redundancy control, that exploits the additional DOFs of the robot in order to avoid collisions between obstacles and robot arm, while trying to keep the attainment of the final task.

Dealing with motion planning for obstacle avoidance, a common approach is to define artificial potentials that drive the robot inside the workspace to the target [3]. The result of the potential fields is a set of forces, attractive toward the goal and repulsive from obstacle regions. Typically such forces are associated to velocities applied to the end-effector of the manipulator; then, the trajectory can be obtained by numerical integration. The same principle can be used in order to avoid collisions between obstacles and control points along the kinematic chain of the manipulator: in addition to the motion imposed to the end-effector, a repulsive velocity vector can be applied to the point of the robot that is closer to one of the obstacles, adding a task to the control system [4].

Furthermore, the problem of passages trough singular configurations must be taken into account, using for example an algorithm for damped least-square inverse kinematics [5].

Starting from the aforementioned approaches, this work introduces some improvements: the off-line path planning is combined with a smoothing interpolation based on Bezier curves in order to avoid sharp edges and high accelerations; regarding the collision avoidance control, an additional term depending on the velocity of the obstacle is introduced, previewing its next position in order to plan the optimal correction of the trajectory. Algorithms are tested in simulation for the 7 DOFs cobot KUKA LBR iiwa. In the future real implementation, the system will be equipped by environmental optical sensors able to detect in real-time obstacles and to provide a virtual model of the environment surrounding the robot [6], [7].

II. Motion Planning and Control Strategy

An algorithm for path planning has been developed based on the artificial potential field approach. As shown in Fig.1, starting from its initial position the end-effector is driven through a field toward the point of minimum potential, i.e. the goal. The presence of obstacles creates local maxima that push away the end-effector if its distance from the obstacle is under a predefined threshold that defines the area of influence of the obstacle. The resulting trajectory, green in the figure, is then interpolated with a 5^{th} order timing law. Then, in order to avoid sharp corners, a further process is done: a closed form fitting procedure is exploited to find the set of coefficients of the 4^{th} order Bezier curve that best fits the original trajectory. The resulting trajectory is shown in Fig.1 in magenta in comparison with the one directly obtained from artificial fields.

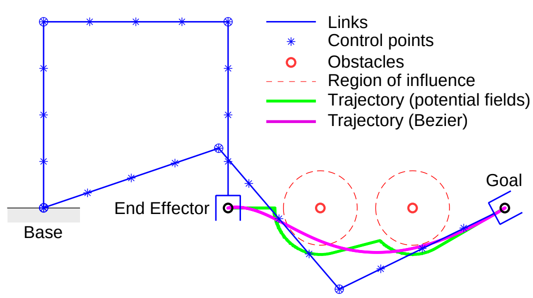

Fig. 1. Example of path planning for a 3R planar robot with a 2-DOF task.

Dealing with motion control of the robot, it is conceived as a velocity control loop based on the following law:

$$\dot{\mathbf{q}} = \mathbf{J}^{\dagger}(\dot{\mathbf{x}}_e + k\mathbf{e}) + (\mathbf{J}_0\mathbf{N})^{\dagger}(\dot{\mathbf{x}}_0 - \mathbf{J}_0\mathbf{J}^{\dagger}\dot{\mathbf{x}}_e) \qquad (1)$$

Basically the joint space velocity vector $\dot{\mathbf{q}}$ is derived as the sum of two terms. The first term is related to the velocity imposed to the end effector ($\dot{\mathbf{x}}_e$) with an additional correction of the error $\mathbf{e}$ between actual and desired position of the end effector. The second term is related to the additional task of collision avoidance regarding one of the control points of the kinematic chain of the robot: $\dot{\mathbf{x}}_0$ is the repulsive velocity assigned to the control point $\mathbf{P}_0$ nearest to one of the obstacles, that is mapped to the joint space by the jacobian $\mathbf{J}_0$ relative to $\mathbf{P}_0$, whereas $\mathbf{J}$ is the jacobian at the end-effector, $\mathbf{N} = \mathbf{I} - \mathbf{J}^{\dagger}\mathbf{J}$ and † denotes the pseudoinverse operator. In order to avoid numerical problems in proximity of singular configurations where singular values of the jacobian tend to zero, the pseudoinverse is calculated using a Damped Least-Square algorithm, that introduces error in position in addition to numerical errors due to integration; for this reason the correction of the error $\mathbf{e}$ in the first term of equation 1 is required, as normally done in CLIK (Closed Loop Inverse Kinematics) controls.

The algorithm has been developed and tested for the KUKA LBR iiwa robot. Several cases have been simulated, with single or multiple, fixed or moving obstacles. Fig.2 shows an example of motion along a vertical trajectory with a fixed orientation of the end-effector. The lower obstacle imposes a deviation from linear motion; during the motion also the upper obstacle interferes with a link of the manipulator, thus the collision avoidance algorithm acts exploiting the redundancy, accomplishing the task till the final configuration shown on the right.

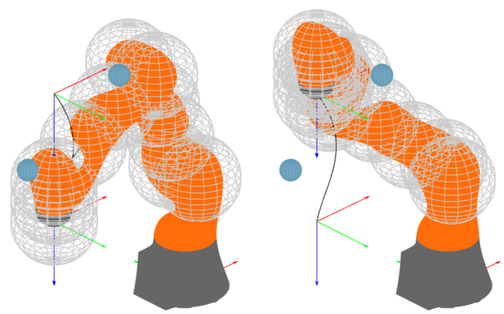

Fig. 2. Example of collision avoidance on KUKA LBR iiwa.

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