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Motion analysis of a mobile manipulator executing pick-up tasks ☆

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ABSTRACT

This paper presents an analysis of a mobile manipulator movement executing a pick-up task. The robot has to reach a target point with its end-effector. The configuration of the manipulator and the pose of the mobile robot define the inputs of the problem.

The random profile approach is applied to deal with the aforementioned issue. The trajectory which minimizes the execution time of the task is generated. Furthermore, the manipulability index is introduced in the optimization process in order to allow a comfortable configuration of the manipulator to reach the target-point. The obtained results in free and cluttered environments are presented and discussed. The feasibility of the computed trajectories is also validated against experimentation, in the case of the RobuTER mobile robot carrying the Ultra-Light Manipulator.

1. Introduction

Robot mechanical structures are mainly classified into fixed-base articulated systems and mobile platforms. The diversity of applications leads to consider an obvious alternative that associates manipulation and mobility aptitudes. A robotic system with these capabilities is typically composed of robotized vehicle (mobile robot) carrying one or more arms.

Planning framework of automated systems is commonly based on two-stage method. First, the path planning which outcomes the path points connecting the query pair, and describes geometrically the motion of the robot. Then, the path is interpolated in trajectory-generation level, with specifying to a timing law.

In this article, a pick-up task is assigned to one-armed mobile robot (RobuTER/ULM mobile manipulator). A target-point (*ITP*) defined in 3D Cartesian space is imposed to the End-Effector (*EF*) of the manipulator. The movement of the mobile manipulator is complex due to its high Degrees of Freedom (DoF) number. Unavoidable mobile robot localization error also occurred due to odometry sensor and initial position of the robot [1].

The redundancy caused by the combination between mobility and manipulation (offering many possibilities to reach *ITP*) is solved using a multi-dimensional trajectory generation methodology. The random profile approach (*RPA*) [2] is employed to the generated optimal trajectory to the system. Execution time (cost function) is minimized. The trajectories are generated in the joint space. Reaching singular configurations and the calculation of kinematic models are avoided. The saturation values of the actuators (velocities and accelerations of the robot actuators) and the non-holonomic constraint of the mobile

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system are respected. *RPA* allows solving varied types of trajectory problems, using diverse types of performance criteria under diverse types of kinodynamic constraints, and has the ability to find near-optimal solutions within competitive run-times [2]. *RPA* is characterized by interesting attributes as versatility, efficiency and simplicity of implementation [3]. Manipulability index is introduced as additional constraint, placing the arm in regular configuration for reaching *ITP*. Pose error transmitted from the mobile system to the *EF* can be corrected by the manipulator, which is adapted to be reconfigured. The analysis of simulation and experimental results regarding the impact of the manipulability as a supplementary constraint, to the *RPA* algorithm (planning trajectories for RobuTER/ULM), is presented in this work.

The rest of this paper is organized as follows. Section 2 gives a brief state-of-the-art of methodologies addressing trajectory generation and pick-up tasks execution issues for mobile manipulators. Section 3 summarizes the characteristics of the experimental robotic system. Section 4 describes explicitly the difficulty to execute the prescribed task. Section 5 explains the concept of the *RPA* and formulates the proposed solution. Section 6 validates the proposed approach in simulation. The real motion of the robot is also analyzed when implementing generated trajectories on RobuTER/ULM.

2. Related works

The context of trajectory planning for mobile manipulators is complicated due to the combination between the mobility of the vehicle and the manipulation of the articulated robotic system. Trajectory planning methods with singularity avoidance and redundancy resolution for one unique-armed mobile system are the principal topics discussed in this section.

2.1. Pick up tasks execution

The execution of pick up tasks by mobile manipulators principally requires the respect of initial manipulator configuration with the mobile robot pose, and the reaching of *ITP* with the *EF* of the arm. One solution might consist of fixing the final pose of the mobile robot, in an area allowing reaching the *ITP* with the *EF*. The best final robot pose can also be calculated with optimizing cost functions [1,4]. The connection between the fixed queries consists of generating a unique feasible trajectory. Polynomial-based obstacle avoidance technique [5], or model-based methods [6] are relevant. However, randomly-sampling based approaches are the most widely used for solving planning problems for mobile and manipulation robotic systems [4]. However, additional processing is needed to obtain feasible trajectories [7]. Operational tasks can also be executed with finding simultaneously the best final configuration and a feasible trajectory. That objective can be achieved with optimization algorithms [8,9].

2.2. Inverse-kinematic and redundancy resolution

The classical way for solving redundancy consists of using approaches dedicated to fixed-base redundant manipulators. Inverse kinematic modeling is discussed extensively in the literature. Analytic approaches can compute closed-form solutions. Such algorithms are, however robot-specific [10]. In the case of trajectory planning for non-holonomic mobile robots, position-level inverse kinematic model is not adequate. It is pointed out to solve the redundancy in velocity level [11]. Jacobian-based approaches are widely used. Operational paths might be transformed into smooth joint space trajectories via the product of exponentials formula [12], with gradient optimization methods [11]. The other oriented-model approach allowing solving redundancy is task-oriented (augmented task space approach). The Jacobian matrix is augmented, so as to tackle additional objectives expressed as constraints [13]. However, there are some principal drawbacks related to those methods. The calculation of the inverse augmented Jacobian matrix is necessary; hence, task execution related to time (continuous) is not appropriate and extra singularities may appear [14].

2.3. Trajectory optimization

Trajectory planning optimization approaches consist of finding optimal movement for the robots satisfying desired mission specifications. The trajectories are constructed with polynomial functions. Performance criteria are introduced in cost function. In the context of mobile manipulation, Korayem et al. [15] proposed trajectory planning strategy based on the combination of the potential field method and optimal control theory. Optimal problem solution is applied based on *Pontryagin's Minimum Principle* (*PMP*). Dong Hun Shint et al. [16] presented a motion planning method for mobile manipulators for which the base locomotion is less precise than the manipulator control. The proposed method finds successive base poses that meet constraints on a measure of manipulability.

Stochastic optimization techniques offer advantages of simpler implementation compared to deterministic techniques. Most common methods applied to solve planning problems include Genetic Algorithms (*GA*) and Simulated Annealing (*SA*). Chen and Zalzala [17] presented an approach for planning optimal trajectories (optimizing torque and manipulability) with *GA* for path following with the end-effector. Fifth order polynomials are used for the mobile platform and manipulator joints trajectories. Zaho et al. [18] addressed path planning problem for a robot which is used to perform a sequence of tasks specified by poses and minimum-oriented force capabilities. In case of multiple tasks execution, Lee et al. [19] divided the problem into two sub-problems (i) trajectory generation with assuming that the commutation configurations are given and,