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1. Introduction

Fixed based manipulators, currently used in industries, have a limited workspace. They are not suitable for tasks such as farming [1], forestry, clearance of military sites [2] or carrying of heavy or large loads [3,4]. So, for such dangerous or unfeasible tasks to be undertaken by humans, the coming out of mobile manipulators is a natural extension of robotics. Mobile manipulators, composed of a robotic arm mounted on a mobile robot, are very interesting systems, particularly in regard to the size of their operational workspace. However, they present various constraints and a lot of interesting problems are merging, due to the coupling of mobile robots and manipulators.

In this paper we focus on the motion generation and control of a particular mobile manipulator composed of a wheeled vehicle and a six-revolute-axis manipulator, thus presenting some non-holonomic constraints (see Figure 1). A point-to-point motion of the manipulator's end-effector is generated off-line and the resulting data are downloaded to the real system for experimental testing. This paper summarizes the approach used for motion generation and focuses on the experimental results for various trajectories. These results show that the steady-state positioning error of the manipulator's end-effector can be important, although very small in simulation. We try to analyze the causes of these errors and propose solutions to improve the experimental results.

Figure 1: LIRMM's mobile manipulator

2. Off-line motion generation

Most people working on mobile manipulators use an arbitrary path and try to follow it. In some cases, the mobile base is holonomic [3]. In other cases, the vehicle is a car-like robot [5]. In this latter case, non-holonomic constraints appear, and they have to be taken into account for motion generation. Despite this additional difficulty, this kind of robot is perhaps the easiest or cheapest machine to develop for real experiments in outdoors environments. It is the choice we have made in our laboratory [2]. For such a non-holonomic mobile manipulator, the path following is more difficult and for some trajectories, impossible. In addition, the goal is frequently to join one point to another, regardless of the intermediate points. The problem is then to compute some via points. One solution is to separate the mobile robot and the manipulator, and to place the manipulator base at a preferential position for the arm, using a mobile robot path planner [6]. This kind of method insures the arm to be in a « comfortable » configuration, but limits the capabilities of the mobile manipulator system. Indeed, the redundancy of the system is not used in this case.

So we consider the global motion of the mobile manipulator from one point to another and we summarize in this section a method to compute a path that takes into account different constraints: vehicle non-holonomy, arm joint limitations, velocity and steering radius limitations... The method consists in computing a sequence of via points reachable by the system and leading to the goal point. This allows the system to automatically generate maneuvers, when necessary. Two displacement representations can be used: homogeneous matrices and dual quaternions [7].

3. Testing the method

In order to test the motion generation method, we have developed a simulator that allows us to generate motions in a convivial way. The results can be displayed in the form of graphs representing the time history of various parameters and in the form of pictures representing the motion of the mobile manipulator (see example of Figure 2).

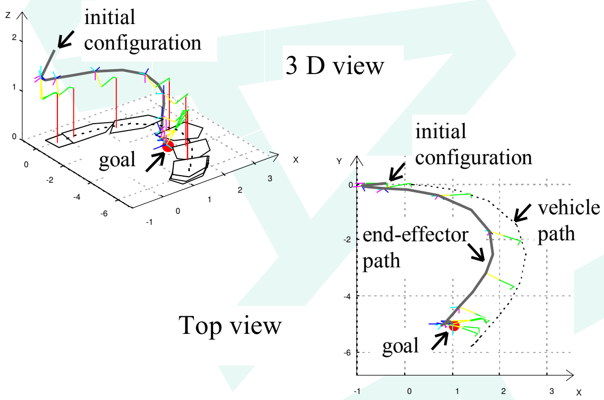

Figure 2: simulation of the mobile manipulator's motion

Once a motion is generated with the simulator, a coordinate transformation module is used to calculate the corresponding joint variables of the manipulator, the rotation angle of the steering wheel of the platform and the wheel velocity of the platform. These data are downloaded to a DSP-based controller that controls the real mobile manipulator and the real motion is performed. In this section, we present in the form of graphs several experimental results corresponding to different motions (with or without maneuvers). It happens that, in particular for complex motions, the steady-state positioning error of the end-effector can be very large. We tried to find the reasons why. To our opinion, errors in measuring geometric parameters on the robot could be one source of errors. The inertia of the system is another source of error. But a major source seems to be the quality of the amplifier piloting the mobile platform (non-linearity, dead-zone).

Therefore, in some cases we have re-computed the motion in simulation in limiting the variation of curvature and the variation of speed of the platform. When the platform has to change its direction of motion, we have modified the data generated by the simulator in introducing a time-delay at null speed. The new results with the real system are presented and exhibit a drastic improvement.

4. Conclusions

This paper showed simulation and especially real results regarding the motion generation and control of a non-holonomic mobile manipulator. Although we have succeeded in performing acceptable motions with the real system, it is clear that reality is far from simulation. In particular, mechanical and electronic technological problems appear to be an important source of error in a complex robotic system. Therefore, even if improvements can be obtained on a theoretical viewpoint, we plan in the future to put some efforts on the quality of the real robot.

On another hand, it is important to point out that the method developed is not only devoted to automatic control of the mobile manipulator. In a teleoperation architecture, high-level commands could be issued from the teleoperator (such as giving only the goal point by means of any teleoperation device) and would require the subsequent use of the motion generator presented in section 2. The problem of teleoperating our mobile manipulator through the Internet is also one of our research topics that is presented in another paper submitted to the 30th ISR.

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