Motion planning for mobile manipulator with keeping manipulability

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Proceedings of the 2002 IEEE/RSJ
Intl. Conference on Intelligent Robots and Systems
EPFL, Lausanne, Switzerland • October 2002

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Abstract

Our research goal is to realize a motion planning for an intelligent mobile manipulator. To plan a mobile manipulator's motion, it is popular that the base robot motion is regarded as manipulator's extra joints, and the whole system is considered as a redundant manipulator. In this case, the locomotion controller is a part of the manipulator controller. However, it is difficult to implement both controllers as one controller, in our implementation experience, because of difference of actuators' character. In this research, we focus on a path planning algorithm for a mobile base with keeping manipulability at the tip of the mounted manipulator. In this case, the locomotion controller is independent from the manipulator controller, and a cooperative motion is realized by a communication between both controllers. In this paper, we propose a motion planning algorithm for a mobile manipulator, and report several experimental results.

1 Introduction

Recently, target environment for activity of robots has been sifting from factory environment to human environment (office buildings, hospitals, homes and so on). Therefore, many research groups and companies had started mobile robotics research. However, comparing with progress of hardware, progress of software (or algorithm) to control robots is still required. Particularly, recent software to control a mobile manipulator is developed with heuristics, and it requires strict conditions in actual environment (for example [1]).

To break above situations, our group researches motion planning algorithms for a mobile manipulator. One of the general approach is to consider the locomotion as extra joints of the manipulator. However, according to our implementation experience, the manipulator controller should be different from the locomotion controller. Thus, we determined that our motion planning approach is, "Path planning for a mobile base with keeping manipulability of the mounted manipulator". Manipulability was defined as a valuation of difficulty of manipulator's operation, proposed by Yoshikawa[2].

In this research, our concrete task is "drawing large objects on a wall by a mobile manipulator." based on above approach. Figure 1 shows an overview of our research task.

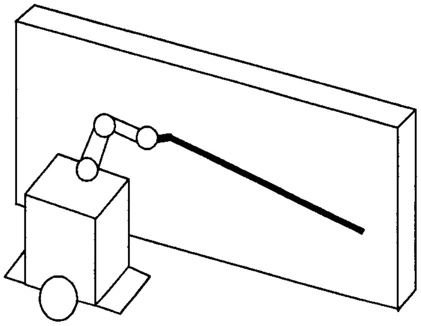

Figure 1: Research Task

To realize above task, one of the biggest problem is that an accumulated error of estimated base robot's position affects a position accuracy at the end-effector. Therefore, the manipulator should have a capability to adjust its pose when the base robot detects positioning errors. Our motion planning approach is reasonable enough to cope with above conditions, because manipulability is considered.

In this paper, we present a concept of path planning algorithm for a mobile base and a motion planning for the mounted manipulator. Finally, we report a simulation and experimental result to verify a validity of this algorithm.

2 Related Works

Research of mobile manipulator includes not only motion planning, but stability of a mobile manipulator, compliance control and so on. Although these fields are vast, included works in here are the works

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that have influenced the authors' thinking.

In heuristics approach, mobile manipulator was used to realize specific tasks. For example, one of my ex-research was to realize a door opening motion by a mobile manipulator (recognizing a door knob, grasping it, and passing through a door-way)[1]. Nakano et al. developed a mobile manipulator with passive joints to realize a door opening motion[3]. In above research, target environment was almost fixed, and motions were pre-planned with heuristics. Thus it was very difficult to discuss generalization.

In non-heuristics approach, Khatib et al. proposed a reactive approach for multiple mobile manipulation systems based on force control [4]. Kosuge et al. also realized a compliance control for a mobile dual-manipulator[5]. It is very useful to generate a reactive motion, however global motion planning is not discussed.

For a global motion planning, "Manipulability" [2] is very useful. For example, Yamamoto et al. used it for a motion planning of a mobile manipulator [6] [7]. Fourquet et al. extended it for a non-holonomic mobile manipulator [8]. According to above, the Manipulability is one of the popular approach for manipulator's motion planning. Our approach is to plan mobile base's path with keeping manipulator's manipulability.

3 Workarea for Mobile Manipulator

3.1 Manipulability

Manipulability is one of the important valuation for considering a manipulator's motion. Particularly, for a mobile manipulator, an estimated positioning errors of the mobile base effects the tip position of the end-effector directly. To absorb the error, the manipulator should move quickly to adjust when the error is detected. Thus we adopt "Manipulability" for our motion planning of a mobile manipulator.

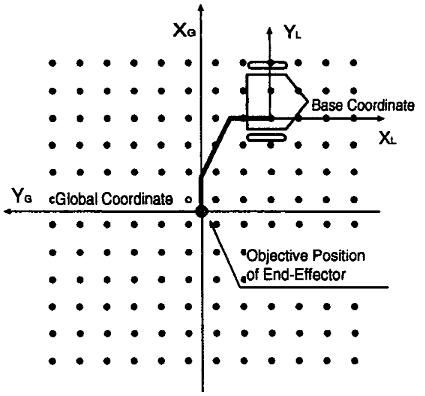
Generally, manipulability w is defined by the Jacobian matrix, shown in following equation.

$$w = \sqrt{det(J(q)J^T(q))} \qquad (1)$$

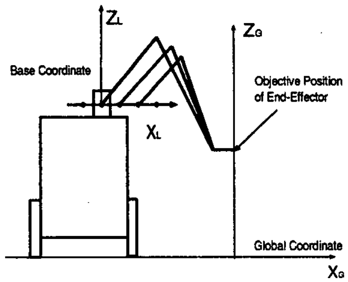
For example, when a manipulator has 6 degrees of freedom, Jacobian matrix is 6×6, and manipulability is calculated by (1) for each pose of the manipulator.

3.2 Distribution of Manipulability

Because of a redundancy that a mobile manipulator has, joint angles are not fixed even if the position and the pose of the end-effector are fixed. The other words, there is a room of choice of the mobile base's position. Our approach is to plan the base's position to keep manipulability. In this research, we assume that a number of degrees of freedom for a target manipulator is six, then a pose of the manipulator is fixed when the base's position is fixed. Thus we can calculate a distribution of the manipulability for each position and pose of the end-effector.



(A) Top View



(B) Side View

Figure 2: Setting to calculate distribution of manipulability

Figure 2 shows a top view and a side view of setting to calculate distribution of manipulability. In (A), each dot is a candidate of mobile base's position. At each point, the value of manipulability is calculated from joint angles that is calculated by inverse kinematics.

We added an extra assumption to avoid kinematic constraint for the mobile base's motion, "1st joint axis is perpendicular to the ground".

Figure 3(A) and 3(B) shows calculated examples of manipulability distributions. $x - y$ coordinate indicates a position of mobile base, and z axis is a value of manipulability. In Figure 3-(B), a value of manipulability becomes smaller and the peak is sharper than Figure 3-(A), because the end-effector (B) is located more difficult position than (A).

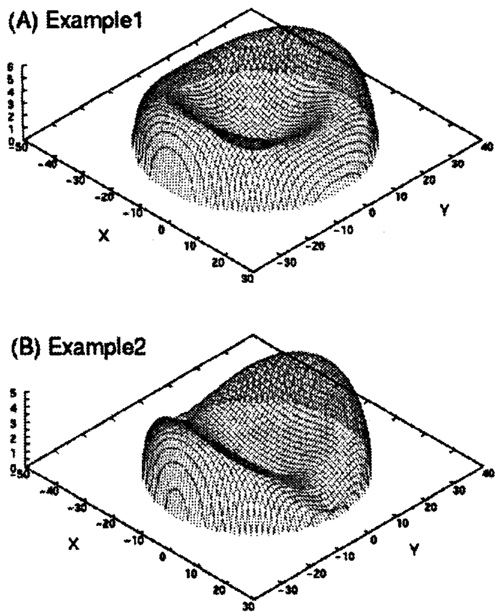


Figure 3: Distribution of manipulability

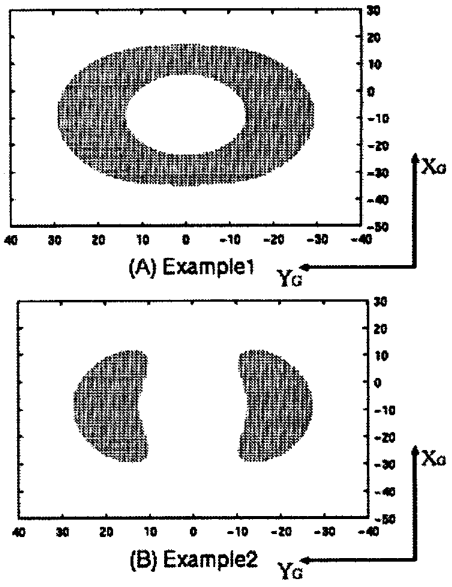


Figure 4: Manipulability Area (MA)

3.3 Manipulability Area

Next step is to determine an area to secure high manipulability, which we call "Manipulability Area (MA)". To generate the area, a manipulability distribution is sliced by a $x - y$ plane (with fixed value of z). Once the mobile base is located in this area, a manipulability is secured higher than a fixed value.

Figure 4 includes two examples of the manipulability area that are applied to Figure 3's example. As this figure shows, a manipulability area usually becomes a shape of a ring (A). The mobile base is impossible to position at the center of the ring, because the manipulator's pose becomes invalid configuration. When the end-effector's position is difficult to pose, a ring shape is cut into two pieces shown in (B).

The fixed value for the slice depends on the manipulator's configuration and the requirement of manipulability. In our case, the threshold value is set as 2.5 heuristically.

3.4 Layer of Manipulability Area

In above sections, we discussed about a desire pose of the end-effector. To execute a specific task (such as drawing segments), the desired pose of the end-effector is changed gradually. Therefore, manipulability area is also transformed according to the change. We piled up a number of manipulability areas (along z axis) that are corresponded to the change. We call this three dimensional shape as "Layer of Manipulability Area (LMA)". $x - y$ coordinate is the same as manipulability area shown in the last section, and z axis is a step of desired pose of the manipulator. (A unit of z axis is completely different from $x - y$ axis.)

Figure 5 shows a general idea of LMA. In this figure, each ring of MA is cut half for display.

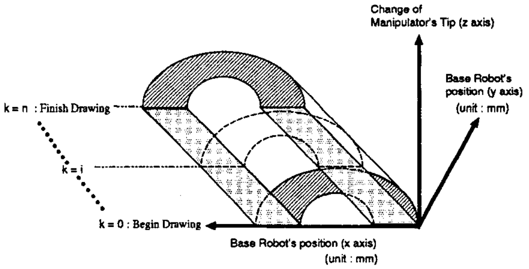


Figure 5: Layer of Manipulability Area (LMA)

4 Motion Planning Algorithm

4.1 Path Planning for Mobile Base

In this section, a motion planning algorithm using a LMA is discussed.

In a LMA, $x-y$ coordinate is a position of the mobile base, and z axis is a procedure flow. A bottom plane of the LMA corresponds to the manipulability area for the initial pose of the end-effector, and the top plane of the LMA corresponds to the manipulability area of the last pose of it. Therefore, a position of the mobile base that keeps a value of manipulability of the end-effector is planned by a path planning in the LMA from the bottom to the top. In this research, we adopt very simple path planning algorithm, as follows.

1. Setting a start point in the bottom plane of the LMA
2. Setting a goal point in the top plane of the LMA
3. Connecting both points by a straight segment, and checking collisions with the LMA's boundary
4. Calculating a distance between both points, if there is no collision
5. Checking all distances, and finding the shortest one

Generally, a positioning error of a mobile robot is accumulated by moving itself. Therefore, We determine an evaluate function as the shortest straight distance in the LMA. If there exists a segment perpendicular to the ground (it is the shortest), it is the best because the mobile base does not need to move.

Finally, this algorithm chooses the shortest segment in the LMA, and it's projection to $x-y$ plane is equivalent to the actual path for the mobile base.

If there is no straight segment from the start area to the goal area without colliding the LMA's boundary, we have to set a sub-goal in an appropriate point in the LMA. (We do not discuss about it in this paper.)

4.2 Motion Planning for Manipulator

Now we specified the mobile base's position corresponding to the desired end-effector's position. Therefore, 6 joint angles at each end-effector's position are determined by inverse kinematics calculation. Finally, we calculate all poses of the manipulator along the mobile base's path.

Keep in your mind that it is degeneracy free approach for calculating inverse kinematics, because we use a value of "manipulability". The value becomes "0" when degeneracy exists.

5 Simulation and Experiment

We implemented the motion planning algorithm proposed in previous section to our mobile manipulator. In this section, we report an example of simulation and experimental result of the robot's motion based on the algorithm.

5.1 Task Definition

A task in this experiment is specified as drawing a segment on a wall. To realize this motion, we assumed that an orientation of the end-effector is perpendicular to the wall, and the target wall is located along x axis. Desired coordinates of both ends of the segment are $(0,0,32)$ and $(0,60,62)[cm]$ (a slope segment).

5.2 Target Robot

Target robot is a mobile manipulator that has seven degrees of freedom manipulator (including end-effector's open/close). An overview of this robot is shown in Figure 6. The base robot has a power wheeled steering, and it can trace straight and curve lines. Specifications of this robot are shown in Figure 7.

A controller of this robot is used as standard PC, and the operating system is "Art-linux" (a real-time linux). The motor control board is used as Okazaki company's board.

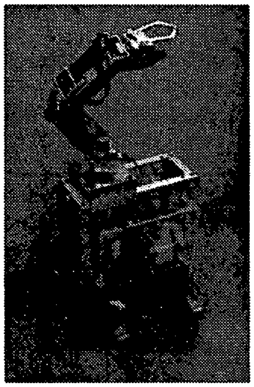


Figure 6: *Mobile manipulator*

5.3 Control Software

To control the robot, there are two layers of programs, "System program" and "User program" in our robot system. "System program" controls basic functions for controlling the mobile base and the manipulator directly (such as velocity control of the mobile base, angular control of the manipulator's joint), which is not changed according to tasks. "User program" includes a set of functions that send motion parameters to the system program, and it is coded for

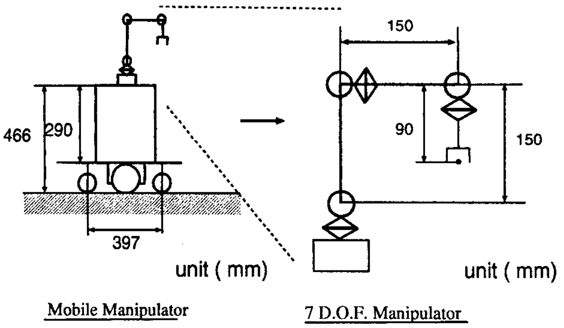


Figure 7: Parameters for experimental robot

each specific task. Usually, users develop a robot's motion by coding "User program".

5.4 Motion Simulator

Before executing an actual motion, we check our planned motion by the "motion simulator" that was developed in our research group.

The simulator is to simulate a behavior of "User program" in a three dimensional virtual space. Robot's specification is the same as the actual robot. A benefit of this simulator is that a "User program" can be executed both the simulator and the actual robot, without changing codes.

5.5 Motion Planning Result

Using our motion planning algorithm, a shape of the LMA and a path planning result in the LMA are calculated shown in Figure 8.

Figure 8 shows two views of the LMA from different viewpoints. A horseshoe-shape area at the bottom of the LMA is a manipulability area for the start point, and the mobile base can be located anywhere in the area at the beginning of the motion. Two base areas at the top of the LMA are manipulability areas for the goal point, and the mobile base can be located anywhere in these areas at the end of the motion. Therefore, path planning in the LMA is done by finding the shortest segment between these top and bottom areas. We implemented the simple algorithm using round-robin check, shown in section 4.1, and the path was found shown in Figure 8, expressed by a black segment. The black segment specifies exact locations of the mobile base (x, y, θ_B) corresponding to desired end-effector's poses. Therefore, each pose of the manipulator $(\theta_1 \cdots \theta_6)$ is calculated by inverse kinematics at each layer.

Keep in your mind that the wall is located on x-axis, and it is not possible for the mobile base to locate inside the wall. Therefore only a half of the LMA is displayed.

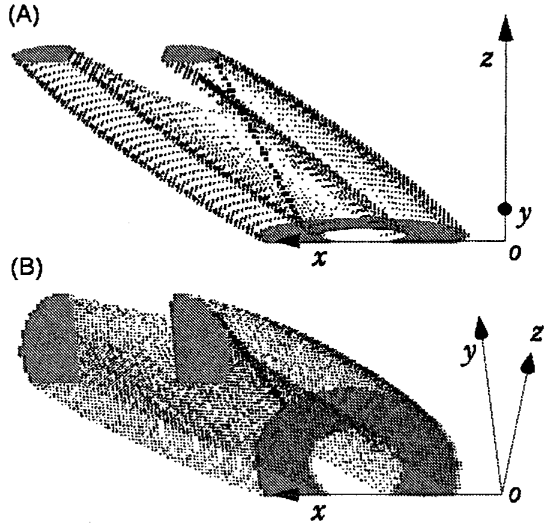


Figure 8: Path planning result in LMA

5.6 Simulation Result

The robot's motion is programmed as "User program" using above planning result. To verify the result, we executed the program in our motion simulator, shown in Figure 9. It is displayed four poses of the robot at once in the same interval. From this figure, we verify that the end-effector traces the desired slope segment while the mobile base moves.

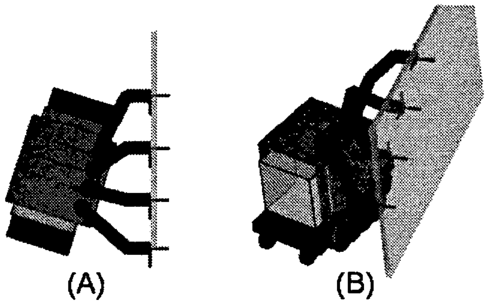


Figure 9: Simulation result

5.7 Experimental Result

We executed the same program in an actual robot in real environment. A motion of the robot is almost the same as our simulation. (Figure 10 shows two snapshots of it's motion.) However it is difficult to draw a desired segment on a wall. One of the reason is an initial positioning error of the mobile base, and it causes straying from the planned path. To solve the problem, extra sensors are required to detect the error, and the robot must absorb it by manipulator's motion.

***Figure 10:** Two screen shots of experiment*

6 Conclusion and Future Works

In this paper, we proposed a motion planning algorithm for a mobile manipulator by keeping manipulability. It enables that one of the redundant motion planning problem (a number of parameter is nine) is simplified into a path planning problem in three dimentional space. We applied the algorithm to one simple task "drawing segment", and verified it's validity.

We still have following future works.

- In our current implementation, we did not consider each joint's limit and reduction gear ratio, and it affects an actual manipulability. To plan a realistic motion, we should consider these factors.
- We assumed that a pose of the end-effector is fixed (perpendecular to a wall), however it does not necessary in some situations. For example, the end-effector can be inclined when the drawing line is located at high (or low) positions. In this case, a construction of "Layer of Manipulability Area" should be changed.
- In our current implementation, the path planning algorithm in the LMA is very simple, and there is no guarantee to find a path (even if it exists). We should consider a mobability of the mobile base, and construct an optimal path planning algorithm in the LMA.

Next step in our research is to realize above topics, and to realize an intelligent motion of a mobile manipulator in real environment.

Acknowledgments

This research is supported in part by a grant from the Japanese Ministry of Education, Culture, Sports, Science and Technology (No.13750223).

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