Motion planning for Mobile Manipulator to Pick up an Object while Base Robot's Moving

Wanli Shan, Keiji Nagatani, Yutaka Tanaka
The Graduate School of Natural Science and Technology,
Okayama University
3-1-1 Tsushima-naka, Okayama 700-8530, Japan
Email: {shan, keiji, field}@usm.sys.okayama-u.ac.jp

Abstract— Our research goal is to realize a motion planning for an intelligent mobile manipulator to pick up an object while the mobile base is moving. This motion is very easy for human. However it includes many technical challenges for robotic research. In this research, we propose a motion planning method for a mobile manipulator with considering the manipulator's manipulability.

In this paper, we describe our motion planning algorithm and introduce a performance of planned motion using three dimensional motion simulator and our actual mobile manipulator.

I. Introduction

Generally, robot manipulators in factories are fixed on ground, and its workspaces are limited (except automated guided vehicles). A mobile manipulator has great benefits from the point of view of large workspace and dextrous motion. Therefore many research groups in universities and companies have been performing researches of mobile manipulators. However, intelligent autonomous motions for mobile manipulators are far from practical use in current technology. Our research objective is to construct a motion planning algorithm to enable an intelligent autonomous motion for a mobile manipulator in a real environment.

One of the challenging topics in research of mobile manipulator is to enable a dynamic-cooperative motion between locomotion and manipulator. If a mobile manipulator performs some tasks while the base robot is moving, an efficiency of working rate can be improved. For example, if a manipulator picks up a target object while its base robot moves, the motion can be performed much faster than a motion "stop, pick up, and go". However, such motion requires reasonable motion planning and accurate sensor feedback control to compensate positioning error of the base robot.

We set our research task for the robot as "the robot picks up a target object while the base robot is moving". In this task, we assume that the robot knows an exact position of a target object and initial position of the robot. Even though such good conditions are assumed, a positioning error at a tip of the manipulator (caused by positioning error of the base robot) prevents its success of the motion. To adjust a relative positioning error between the target object and the end effector, we assume that the robot has an "eye-in-hand system". In this motion, "smooth adjustment" for manipulator should be considered in its motion planning stage, because the smoothness depends on the manipulator's pose and the base robot's path.

In this research, we aim to construct a motion planning method for "smooth adjustment motion" to enable the proposed task. Concretely, path and speed of the base robot are focused in the motion planning.

In this paper, we introduce a motion design and a planning algorithm for picking up a target object for mobile manipulator. Finally, we report implementation topics to verify a validity of the algorithm.

II. Related works

The research area on mobile manipulators is vast. Therefore the researches included here are those that concerns motion planning of cooperative motion between locomotion and manipulator.

Using the heuristic approach to control mobile manipulators, several researches aimed at realizing specific tasks. For example, one of our previous researches involved the realization of a opening door motion by a mobile manipulator [1]. In this research, the robot recognized a target door knob, grasped it, opened the door, and passed through the doorway. Nakano et al. developed a mobile manipulator with passive joints for opening door [2]. In the above researches, the target environment is predetermined, and both the motions are pre-planned heuristically. Therefore, it is very difficult to discuss a generalization of above methods.

Khatib et al. proposed a non-heuristic reactive approach for multiple mobile manipulators that is based on force-control [3]. Kosuge et al. also realized a compliance control for two manipulators that is mounted on a mobile robot [4]. Both researches are very useful for a reactive motion of mobile manipulators. However, global motion planning is not discussed.

In this paper, we propose a motion planning method for a mobile manipulator to enable "pick up a target object while the base robot is moving".

III. Motion design

A. Task definition

In this research, we define our concrete task as "the robot picks up a target object while the base robot is moving". In this task, we assume that the information of target object (size, position etc.) is known, and the initial position of the mobile manipulator is also known. We also assume that there may be some obstacles around the object (but there is a space over it).

B. Task analysis

When a mobile manipulator navigates in an environment, a positioning error of the base robot will be accumulated, and the error affects a positioning error of the end effector. Because of the error, the end effector may fail to pick up the target object, even if the robot knows precise position of it. To detect the relative position of the target object, sensor feedback using "eye-in-hand system" is very effective for success of such tasks.

On the other hand, we assume that obstacles may be located around the target object. Therefore, it is dangerous that the end effector approaches to the target object from the front or side direction. So, the end effector should approach toward the top of the target vertically, and lift up it.

Before a motion of picking up, to adjust its relative position toward the target object using an eye-in-hand system, the end effector should keep the relative position while the base robot moves.

C. Concrete motion design

Based on the analysis shown in the previous section, we designed a motion of the end effector as follows.

1) The end effector is controlled at right above space of the target object.
2) The position of the end effector is adjusted by an eye-in-hand system.
3) The end effector is moved toward straight down to grasp the target object.
4) The end effector lifts up the target object vertically.

Note that the base robot should follow a straight line while the end effector performs above motions to enable the proposed task.

Fig.1 shows an image of the proposed task. The robot grasps the target object while the base robot follows a straight line.

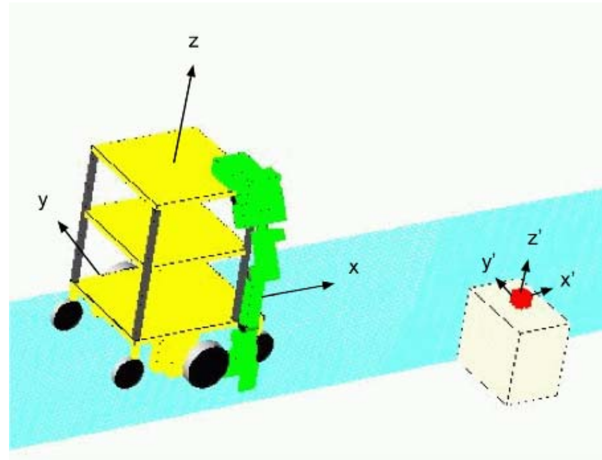


Fig. 1. Target environment

IV. Motion planning method

A. Overview

By considering assumptions that are shown in the section III, we understand that the important parameters for our motion planning are "path and speed" of the base robot. Because of redundancy of the mobile manipulator, there are many candidates of the base robot's path to follow. Once the path is chosen, a series of the manipulator's poses is simultaneously calculated by relation between the base robot and the target object.

For motion planning of a mobile manipulator, Yamamoto et al. proposed that a motion planning of the base robot to maximize mounted manipulator's manipulability [5].

Basically our approach is similar to their research from the point of view of "manipulability based motion planning". However we use the manipulability to limit manipulator's workarea. In this research, we use the concept of manipulability area proposed in [6], and enables motion planning as following procedure.

1) Calculating a distribution of manipulability in its workspace
2) Setting up the manipulability area
3) Choosing the longest segment in the manipulability area to maximize workspace (and it becomes the base robot's path)

Once the base robot's path is planned, a series of the manipulator's poses is automatically calculated by relation between the position of the base robot and the position of the target object.

B. Manipulability

When a positioning error of the base robot is detected by the robot's external sensors, the robot should adjust manipulator's pose quickly and smoothly in order to compensate for the error. Manipulability is one of the important parameters to evaluate such a smooth motion for manipulators [7]. Generally, the manipulability ω is defined by the Jacobian matrix $J(q)$, shown in the following equation,

$$\omega = \sqrt{det J(q) J^T(q)}. \quad (1)$$

C. Manipulability area

In order to realize a smooth motion to compensate relative positioning error of the end effector, the manip-

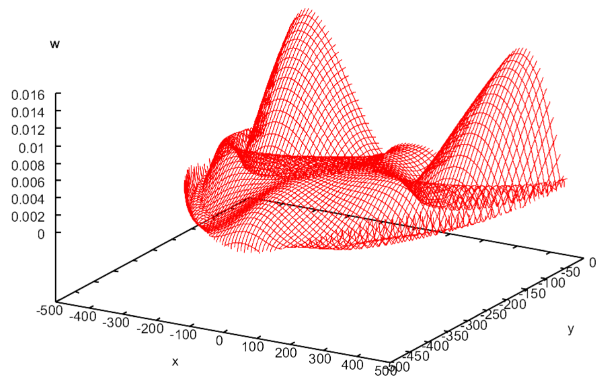


Fig. 2. Distribution of manipulability (z=330mm)

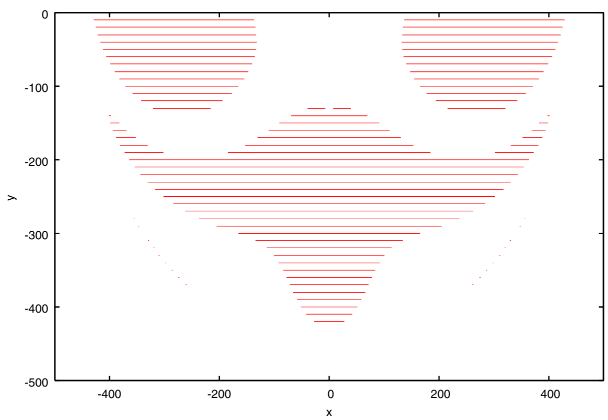


Fig. 3. Manipulability area (z=330mm)

ulability should be kept high in any manipulator's pose. The manipulator's pose depends on where the base robot is located (in case of six degrees of freedom manipulator). Then, distribution of manipulability can be constructed using equation 1. To determine the base robot's workarea, we define "manipulability area" by setting a threshold to keep manipulability high [6]. It is guaranteed that manipulator's manipulability is larger than the threshold when the base robot is inside of the area. In our task, the end effector keeps right above the target object while the base robot is moving.

Fig. 2 shows an example of distribution of manipulability, and Fig.3 shows manipulability area of the example. Details of these figures are shown in section V.

D. Path and motion planning

A straight line is easy to follow for a mobile robot. On the other hand, it is important for our smooth adjustment motion of the end effector to keep it as long as possible at the above position of the target object. Therefore the longest segment in the manipulability area is good for the base robot's path. In this research, we defined that an evaluation of the motion planning is to maximize the length of the straight segment in manipulability area.

Once the path of the base robot is determined, each manipulator's pose can be calculated using inverse kinematics calculation.

V. Implementation and experiment

We implemented the motion planning algorithm (proposed in the previous section) to our mobile manipulator. In this section, we introduce implementation topics, a simulation result and experimental result of the robot's motion.

A. Concrete task and conditions

The task we aim to realize in this research is "the robot picks up a target object while the base robot is moving". We define a detail of the task in this experiment as follows.

First, the initial position of mobile manipulator is set as the origin of the world coordinate system. The position of the target object is set at the position (x= 2.0[m], y= 0.5[m], z= 0.3[m]) in the world coordinate system. The size of the object is 50mm × 50mm × 60mm.

We also assume the following conditions.

1) The position of the end effector is controlled at the height of 50 [mm] from the object.
2) It requires 5 [sec] to adjust a relative position of the end effector (using "eye-in-hand" system).
3) The approach speed of the end effector to the object is 10[mm/sec]. Therefore, it requires total 5[sec] for grasping.
4) It takes 1[sec] to close parallel fingers.
5) It takes 1[sec] to lift up the target object.

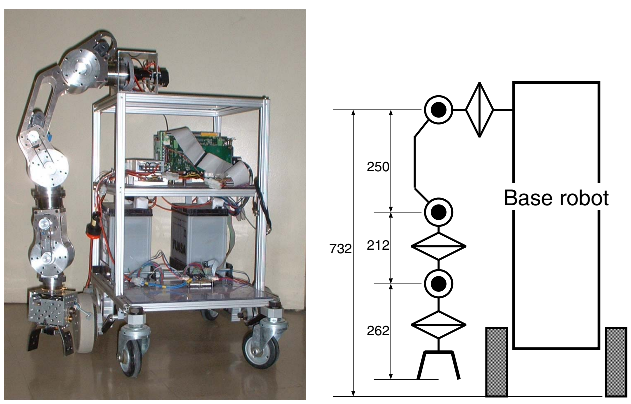
Based on above conditions, we set the end effector's orbit as,

$$\begin{aligned} x(t) &= -v_{base} \quad (0 \le t \le 12) \\ y(t) &= 0 \quad (0 \le t \le 12) \\ z(t) &= \begin{cases} 50, & (0 \le t \le 5) \\ 50 - \nu_{down} \times (t-5), & (5 < t \le 10) \\ 0, & (10 < t \le 11) \\ \nu_{up} \times (t-11), & (11 < t \le 12) \end{cases} \end{aligned}$$

in the global coordinate system, where v_{base} is the speed of the base robot that follows a planned path.

B. Target robot

Target robot is a mobile manipulator that has six degrees of freedom manipulator. An overview of this robot is shown in Fig.4(a) and Fig.4(b). The base robot uses "power wheeled steering", and it enable to trace the robot on straight lines and curves. The controller of this robot is used as standard PC. The operating system is "Art-linux"(a real-time linux).



(a) Photograph (b) Joint allocation

Fig. 4. A target robot "Ron"

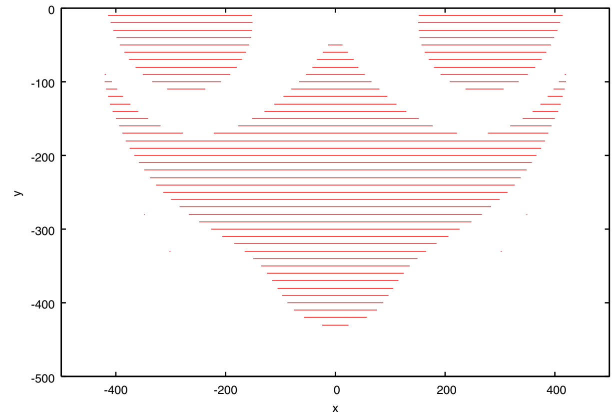


Fig. 5. Manipulability area(z=355mm)

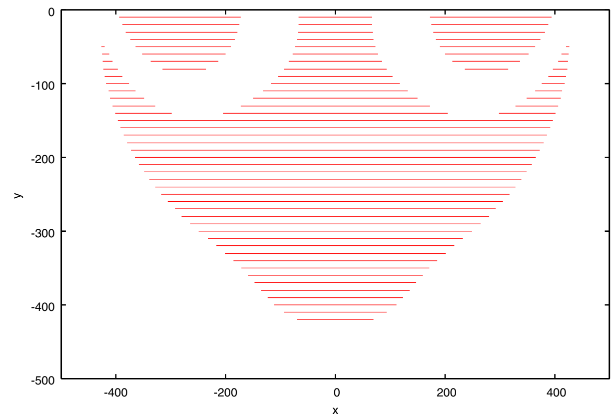


Fig. 6. Manipulability area(z=380mm)

C. Motion Planning

We implemented the motion planning algorithm shown in section IV-A. We introduce a procedure of our motion planning using the following example.

First, we calculated the distribution of manipulability. Fig.2 (shown in section IV-C) displays a result of distribution of manipulability at z=330mm. (In this case, the end effector is located at the same height as the target object.) By using the distribution and the threshold value (0.003 in this case), a manipulability area was defined shown in Fig.3.

Using the above procedure, we also calculated the manipulability areas at z=355[mm] (25[mm] above from the target object) shown in Fig.5, and z=380[mm] (50[mm] above from the target object) shown in Fig.6.

In this implementation, we calculate the logical product in above three manipulability areas, shown in Fig.7. In the area, we chose the longest common segments that becomes the base robot's path.

Once the base robot's path was fixed, its navigation speed was automatically determined by using the assumptions shown in section V-A. (In this implementation, 12 [sec] is required for whole motion.) Manipulator's pose (at each position of the base robot) was also calculated by the inverse kinematics calculation.

D. Motion simulator

Before executing a planned motion for our mobile manipulator in a real environment, we checked the motion by the simulator that was developed in our research group.

An aim of the simulator is to simulate a behavior of "motion program" in three dimensional virtual space in computer. Robot's specification is the same as the actual robot, and the "motion program" can be executed directly in both the simulator and the actual robot.

In this research, we developed "motion planner" and "motion program" to realize our task. The "motion planner" generates a path of the base robot and a series of the manipulator's poses, which is calculated by the proposed algorithm offline. On the other hand, the "motion program" controls a cooperative motion between locomotion and manipulation online. After execution of "motion planner", we executed "motion program" in the simulator, and the result is shown in Fig.8. The simulation result had no problem, and we guess that the motion can work well in a real environment.

Note that the simulator does not simulate a positioning error of the base robot, so there is no guarantee of reasonable motion in a real environment (even if it worked well in the simulator). However, we can check a feasibility of motion planning result using this simulator.

E. Motion in a real environment

We executed "motion program" in our mobile manipulator "Ron" that is shown in Fig.4(a). Currently, the planned motion is performed without sensor feedback. The motion performed in the real environment is shown in Fig. 9.

The motion result in this figure seems successful. Therefore it is verified that the planned motion can be

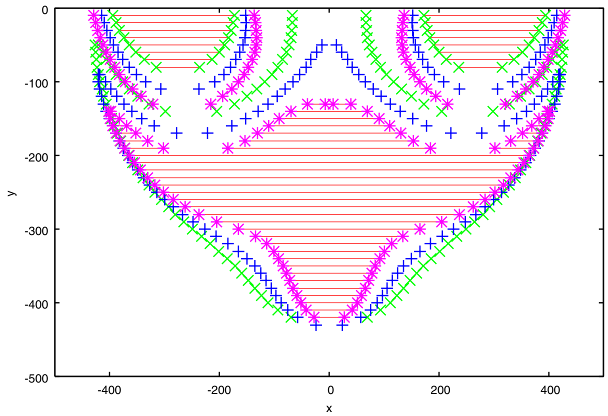


Fig. 7. Logical product of three manipulability areas

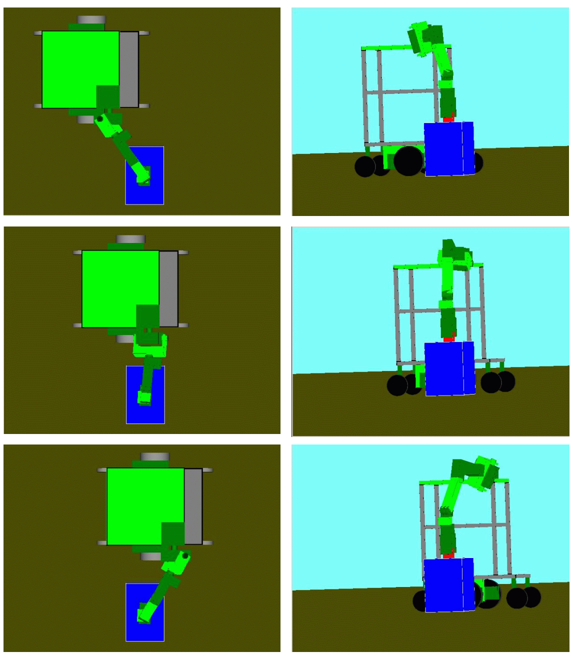


Fig. 8. Animation of planned motion

performed in an actual environment. However, in our current implementation, the motion failed in many cases because there is no sensor feedback for adjustment of the relative positioning error. We are now working on developing an adjustment function of the end effector's position by visual feedback method.

We also found that the speed of the robot was too small to find a merit of coordination of locomotion and manipulation. A part of the reasons is the speed limitation of our manipulator's joints. However the main reason is a binding condition of the motion planning. In our current implementation, the end effector stays at above the target object, and it prevents fast motion of the robot.

Fig. 9. A series of motion in the real environment

VI. Conclusion and Future Works

In this paper, we proposed a motion planning algorithm for a mobile manipulator to enable a task of "the robot picks up a target object while the base robot is moving". Simulation and experimental results supported the validity of the method.

Future works in our research are as follows.

1) Performance of the proposed task with sensor feedback to adjust end effector's position in a real environment
2) Motion planning for mobile manipulator to pick up a target object that is faster than current motion

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