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Optimal Position of Mobile Manipulator with One Degree-of-Freedom Device Constraint

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Abstract— ***This paper presents a methodology for finding an optimal position for a mobile manipulator to handle devices with one degree of freedom (DOF), such as a refrigerator or drawer. When an object has one DOF, it works as a constraint against a manipulator. The manipulability changes during an operation on an object, because the position of a mobile platform has a great effect on the efficiency of the work. This study focuses on the optimal position for the mobile platform of a mobile manipulator on the basis of the manipulability measured during a manipulation job on a target device with one DOF.***

Index Terms—**Optimal position, Manipulability, Mobile manipulator, Device constraint**

I. INTRODUCTION

A mobile manipulator can be widely used in the service robotics area, especially in a home or office environment, because it combines the merits of a manipulator and mobile platform. In addition, the need for it is increasing in industrial areas because of the advantages of its extended workspace. A mobile manipulator consists of a manipulator mounted on a mobile platform, and it inherently has redundancy regardless of the degrees of freedom (DOFs) of its robotic arm because a mobile platform adds 3 DOFs to an arm. Thus, it is not easy to operate such a system because it has many DOFs and requires a solution for its redundancy. To solve this problem, a unified kinematics analysis is required to combine the kinematics of a robotic arm and a mobile base, and many studies in this field have been performed over the last several decades. The results suggest a unified kinematic solution in which the redundancy of a combined system increases because the DOFs of a mobile platform are added to those of a robotic manipulator. From the viewpoint of the manipulability as a quality of the kinematic structure, this unified kinematic solution should be considered. in this paper, we discuss a manipulation target with one DOF, like the door of a room or a desk drawer. If a mobile manipulator is used in a home or office environment, this may often be the case. When handling such devices, the motion of the manipulator is constrained by the target, in contrast to constraint-free targets, because the door of a room or a desk drawer only moves in the direction of the designed DOF. Thus, the constraint of a target device should be considered in the motion planning of a mobile manipulator, i.e., the degree to which the door would be opened or the length to which the drawer would be drawn. From the viewpoint of the relationship between a robot and a device, we call this problem "robot-device interaction," like HRI (human-robot interaction). Actually, the only response of a device is the direction of its movement, and such information must be known to a robot in advance to manipulate that device properly. One of the most important things to consider in this problem is the initial position of the mobile manipulator when the manipulation starts. For an industrial manipulator, the base position of the manipulator is fixed. However, a mobile manipulator may choose its starting position. If no constraint exists for the target device, the starting position is not very important because the picking job will be conducted at one point in the task space. However, the manipulator may suffer reduced manipulability while conducting the manipulation job in the case proposed here for an arbitrary initial position because the position of the end-effector should move along the path constrained by the designed direction of the target device. To solve this problem, this paper proposes a methodology to find the optimal position of a mobile platform to enhance the manipulability when a mobile manipulator tries to handle a device that is constrained by one DOF with the assumption that the mobile platform does not move during the manipulation to increase the accuracy of the manipulation job. A manipulability map can be constructed for possible locations of a mobile platform with the given joint limits of a manipulator, and thus the position of maximum manipulability can be obtained during the operation of a robotic arm. This paper is organized as follows. Section II describes a device with one DOF from the viewpoint of robot-device interaction. Section III discusses the manipulability as the working ability of a mobile manipulator, along with a method to find the optimal position on the basis of the manipulability measure. Simulation results for a case study are presented in Section IV, and conclusions and proposals for future work are given in Section V.

II. ROBOT-DEVICE INTERACTION—STUDY ON DEVICES WITH ONE DEGREE OF FREEDOM

There are many devices with a one-DOF constraint in our daily surroundings: the door of a room or closet, the drawer of a desk, the door of a refrigerator or microwave oven, the drawer of a kitchen cabinet, etc. (see Fig. 1 and Fig. 2). If there is no device constraint, a robot manipulator can manipulate the device freely after grasping it, while considering the collision avoidance problem. In this case, the only constraints are derived from the robot itself, such as from the limits of each joint, and from the environment, such as

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from another object nearby. However, a device that has a one-DOF constraint places a restriction on the moving path of an end-effector of a manipulator. Thus, the path stipulated by the constrained device should be considered when planning the path of a robotic arm to handle that device. To solve this problem, in addition to recognizing an object and finding gripping points, information about the constraint of a given device should be obtained, i.e., semantic information about the device should be given in advance. This means that constraints are given not only by the robot and other objects but also by the target device. This can be handled in several ways. The most common method is to depend on the ambient intelligence. Semantic information about objects that are manipulation targets is stored in a server and can be fetched after a robot recognizes an object. To enhance the accuracy and speed of the object recognition, some landmark information can be attached to the object and used as a code. After receiving the manipulation command and finding the target device, the needed information can be transferred from the server.

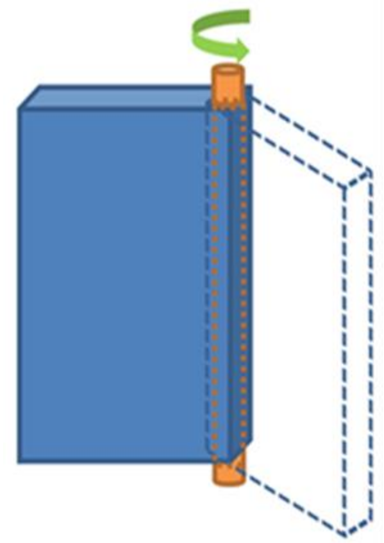

Fig 1 Door and its direction of motion

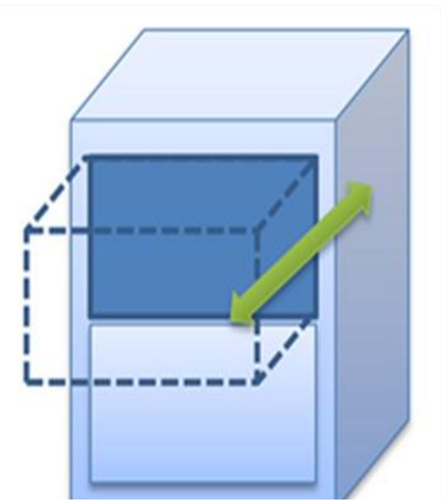

Fig 2 Drawer and its direction of motion

The required information includes the shape and size of the device, the constraint condition, and DOFs. Then, the robot can plan its moving path to conduct the commanded job. We call this problem "robot-device interaction," where some information is given by a device, and manipulation is supplied by a robot like in human-robot interaction, which has been an active research field in recent years. A device could be either passive or active. Actually, the only response from a device is the direction of its movement, and such information must be known to a robot to operate that device. Even though it is not necessary to restrict the DOFs of devices, the problem is confined to the case of manipulating a device with one DOF because many objects in our surroundings have one DOF.

III. OPTIMAL POSITION BASED ON MANIPULABILITY

A. Manipulability

Manipulability is widely used to solve a redundancy problem in a robotic arm. The concept of manipulability was defined by Yoshikawa [1] as a continuous measure that evaluates the kinematic quality of robotic mechanisms; he called it the measure of manipulability (MOM), and it has been extended to several cases [2], [3]. Doty et al. suggested dynamic manipulability on the basis of screw theory [4]. In particular, manipulability is a critical issue for a mobile manipulator because of the redundancy [5]. Because many manipulators have six or seven DOFs, and a mobile platform has at least two DOFs, a mobile manipulator has eight or more DOFs. Thus, such a system is redundant, and this redundancy problem should be solved on the basis of the unified kinematic solution. The MOM of a mobile manipulator was studied by various researchers in several ways [5], [6], [7].

The definition of MOM, which was proposed by Yoshikawa and is widely used to measure the kinematic quality, is given as follows [4].

$$MOM = \sqrt{\det\{J(\theta)J^T(\theta)\}}$$

where J is a Jacobian matrix, and MOM is nothing but the product of singular values. This is a common index for manipulability.

B. Proposed Algorithm

In this section, a methodology to determine the optimal base position of a mobile platform is proposed. The optimal base position problem has been studied by several researchers [8], [9]. However, the problem of manipulating a door until it is open 90° is discussed in this paper on the assumption that the initial joint position of a manipulator is given. The optimal position will be found on the basis of the manipulability described in the previous section. That is to say, by measuring the change in manipulability by following the moving path of a door during manipulation, the position at which the manipulability is maximized can be selected as the optimal position. The detailed procedure is as follows.

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1) Calculate the size of a door and trace the revolution from the rotation axis on the basis of the given device information.
2) Find a collision-free area between the mobile platform and the target device
3) Select some candidate points for the initial position of a mobile platform while considering the workspace of a manipulator and the path that it should follow.
4) Measure the change in manipulability during the manipulation starting from one of the candidate initial positions of a mobile platform.
   a) Calculate the manipulability for all the sampled points after selecting the initial joint angle of a manipulator by solving the inverse kinematics.
   b) Calculate the manipulability by solving the inverse kinematics for all the sampled points on the path of the end-effector.
5) Find the minimum value of manipulability and the position of a mobile platform corresponding to this minimum value.
6) Search for the minimum value of manipulability for all the candidate initial positions of a mobile platform
7) Find the maximum value among the minimum values of manipulability found for each candidate initial position of a mobile platform in step 6).
8) Select the position of a mobile platform that matches the maximum value found at the previous step as the optimal initial position.

As described in Section I, we assume that a mobile platform does not move during manipulation to enhance the accuracy of a commanded job.

IV. SIMULATION RESULTS

The proposed method is now shown through some numerical simulations. The mobile platform is assumed to be omni-directional, and thus it can move in any direction. The shape of the mobile platform is square and the size is 65 cm × 65 cm × 50 cm (width × length × height). A manipulator with seven DOFs is chosen and mounted on top of the mobile platform in the middle of the square. The simulation is conducted using Matlab™ by MathWorks. The motion of the mobile manipulator is shown in Fig. 3 (Fig. 3(a) is the top view and Fig. 3(b) is a side view). As the target device, the door of a refrigerator is considered. An opening angle of 90° is chosen for the door, and thus the door will be rotated by 1/4 of a circle. Considering the workspace of the manipulator and the collision-free area between the mobile platform and the fridge, the candidate area is selected. It is shown in orange in Fig. 4. The coordinate system is also shown. The trajectory of the door is also described as a dotted line. The left side of the green line represents the collision-free area between the mobile platform and the fridge. The blue double circle represents the possible area in which the start position and arrival position of the handle of the door is included in the reachable space of the mobile manipulator. After dividing this area by a grid size of 1 cm, the manipulability is measured for all candidates. Fig. 5 shows the distribution of the minimum value of manipulability corresponding to each candidate position of the mobile manipulator. However, this area includes unreachable space because of the joint limits of the mobile manipulator. After removing the unreachable space, the distribution of the minimum value of manipulability is described in Fig. 6. Then, the optimal base position is determined to be (x, y) = (0:825, 0:62), at which the manipulability is maximum. Fig. 7 shows the trajectory of end-effector and the changes of measure of manipulability when a mobile platform is at the optimal base position while a robot opens the door of fridge (Fig. 7(a), 7(b), 7(c) shows the position of end-effector and Fig. 7(d) shows the measure of manipulability).

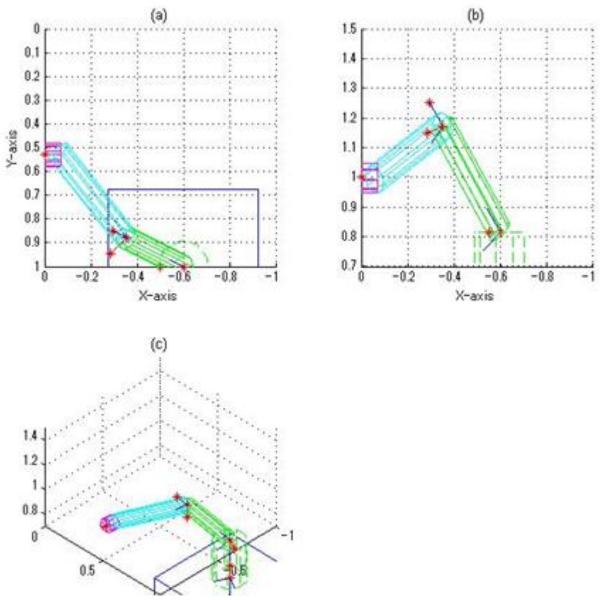

Fig 4 Motion of mobile manipulator

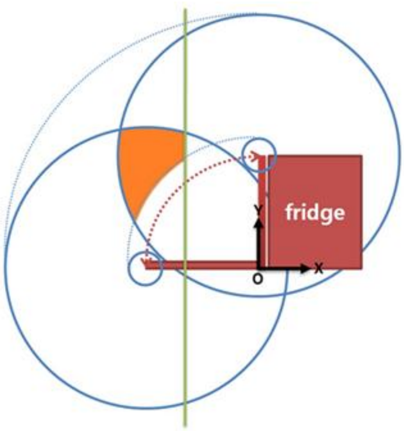

Fig 3 Candidate area of mobile platform

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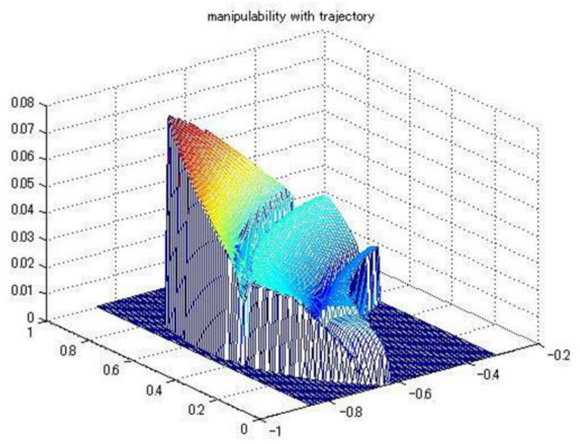
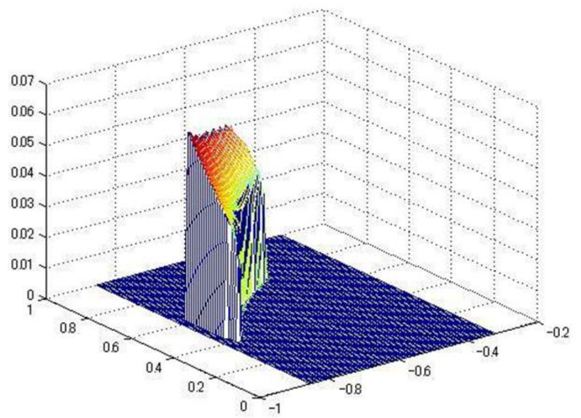


Fig 5 Distribution of minimum value of manipulability (before



removing unreachable space)

Fig 6 Distribution of minimum value of manipulability (after removing unreachable space)

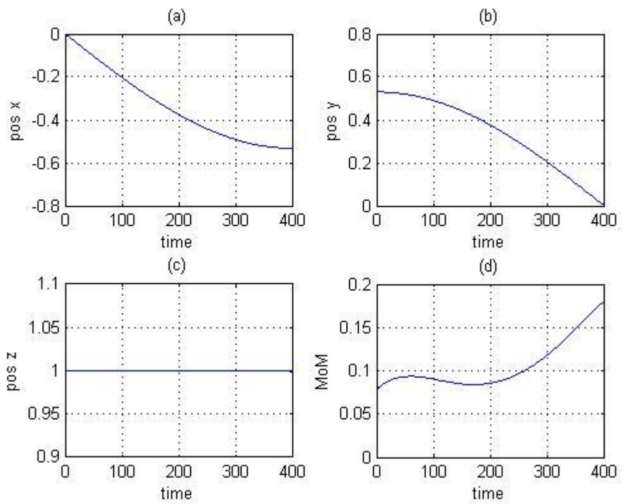


Fig 7 Trajectory of position and MoM

V. CONCLUSIONS AND FUTURE WORK

This paper proposed a method to determine the optimal base position of a mobile manipulator to handle devices with one DOF from the viewpoint of the manipulability. The concept of robot-device interaction was introduced. In this interaction, information is given by a device and manipulation is provided by a robot like in human-robot interaction. Simulation results were provided for the case of opening the door of a refrigerator. In future work, we will address the application of the proposed method to devices with other kinds of constraints.

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