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Twisting Door Handle with Manipulator under Uncertainty

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Abstract - The paper presents a door opening strategy, a twisting door handle strategy, with a manipulator under uncertainty. The door opening is one of the basic yet important functions of mobile manipulators in operating in human environment. However, it can be a difficult task when the information about the door handle is not complete. In this paper, it is proposed to use compliant motion control and the motion constraint of the door handle to overcome the limitation of uncertain information. Specifically, the center of rotation point of the door handle is estimated while compliant motion control is applied in order to complete the door handle's twisting action. The performance of the proposed strategy is demonstrated by the experimental results.

Keywords - twisting door handle, uncertainty, manipulator, compliant motion control

1. Introduction

There are increasing demands on intelligent robots that make human life easier. Nowadays a mobile manipulator is one of the most realistic forms of the robots that could be used in human lives. Manipulators used in manufacturing factories perform their repetitive tasks in free space, meaning the manipulators are not in contact with the environment [1]. However, a mobile manipulator in human environment, a form of a mobile rover with a manipulator on top, has to perform various and complex tasks under uncertain environment. Compared to the factory robots, a mobile manipulator is required to navigate human environment such as office space or home.

Door opening is basic yet critical task for the mobile manipulators since they need to get through the doorways while navigating human environment. This door opening task for a mobile manipulator itself is not a trivial but challenging task, because the door and door handle are dynamic objects and their information, such as geometry, is not easy to be obtained accurately. This paper proposes a door handle twisting strategy under the uncertain information of the door handle, especially the center of rotation, with the hypothesis that the door handle is a lever type door handle.

Obtaining the target object's characteristics is an important process for a mobile manipulator to perform its task. It requires various senors to acquire necessary information. The data from the vision sensors depend on many factors such as temperature, brightness, and reflection. Also, sensor calibration is an important factor to acquire accurate data from the sensors. Moreover, to acknowledge the target object's geometrical characteristics, it requires accurate information from stereo camera, or the object's geometrical mesh model has to be implemented beforehand. These processes not only require strong computation and sophisticated algorithm but also provide imperfect information. In addition, getting mechanical characteristics of the target object, such as stiffness and friction, are impossible unless the manipulator makes contact to the object. Therefore, a robust control strategy with proper estimation methods is critical for the manipulator to complete its task with an object under uncertainty.

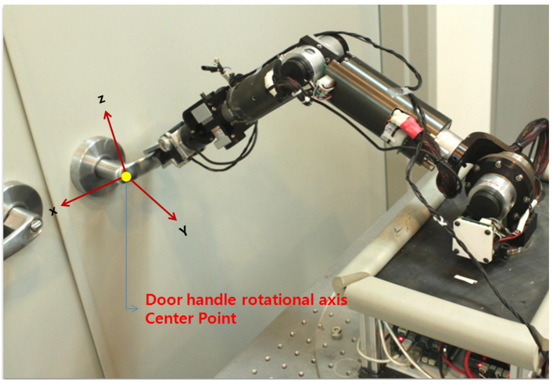

Fig. 1 Image showing 6DOF SAP1 manipulator grasping on the door handle. The axis shown on this global frame axis from the manipulator base, and yellow circle is the door handle rotational axis center point.

The proposed strategy in this paper combines a compliant control framework with an estimation method to overcome uncertain geometrical information of the door handle in the door opening task. Its performance and efficiency are shown by demonstrating door handle twisting task using 6DOF SAP1 manipulator (see Figure 1). First, when the gripper makes firm grasp on the door handle, it starts to control motion with the initial rotational center point of the door handle, which is very off value from the actual rotational center point. Second, while the manipulator is controlled with the operational space framework, the center of rotation point of the door handle gets estimated. This estimation is being conducted in real-time so that this estimated center of rotation point of the door handle is fed back to the controller. Therefore, the control and estimation is strongly coupled to successfully twist

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door handle while reducing the uncertainty of the door handle position.

2. RELATED WORK

Subject of opening door with mobile manipulator has been studied since early 1990s, and recently began to get broad attention. There are two major topics to door opening problem. One is detecting and identifying door and door handle, and another is the strategy of opening doors [2].

Many intensive researches are performed on identifying doors and door handle with computer vision, and sensor algorithm [3], [4], [5], [6]. However, These researches are more focused on computer science based object recognition algorithm which is the previous step in order to perform twisting door handle task.

Research on opening door with mobile manipulator in human environment was first suggested in early 1990s [7], [8], [9]. In [9] vision sensor mounted on top of the manipulator is used to detect the door handle and rotates the door handle to complete door handle twisting motion. If the the door handle is a knob type, rotating the knob is a simple orientation control, but it can not apply to lever type door handle. Also in [9], it was not considered the case when the vision sensor fails or the gripper does not grasp the center of the door knob.

In [10] compliant motion control with force/torque sensor is used to compensate the estimated error of the radius of a door, but twisting the door handle is not considered. It assumed that door handle is completely twisted enough to open the door, and the gripper firmly grasped onto the door handle while the mobile manipulator completes door opening motion.

In [11] the manipulator executes twisting the door handle by pre-planned trajectory, acquiring 3D model of the door handle in advance. It uses Bayesian estimation to determine the position and orientation of the door handle. In [12] vision-based learning algorithm is used to extract 3d key locations that detect the location of the door handle. Based on the 3d key locations, it executes pre-planned trajectory and completes door handle twisting action. However, it is not discussed the case when pre-planned trajectory is incorrect or unexpected event occurs such as slip of the door handle during twisting.

3. APPROACH

For the gripper to rotate the door handle, compliant motion control is applied using the operational space control framework. The position of the gripper is commanded to follow a desired trajectory whereas the rotation about y-axis is to be compliant with the door handle (Figure 2). This is because the estimation algorithm of rotation center of the door handle requires that the gripper is aligned to the door handle. While the gripper rotates the door handle compliantly aligned with the door handle, the rotation center is being estimated and this estimated point is again used for creating rotating motion of the gripper in real-time.

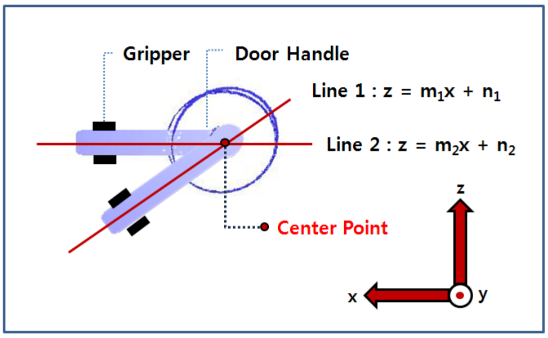


Fig. 2 Images showing brief description of lever type door handle and its straight line consisting along the rotation of the door handle. The Center Point is obtained by the intersection point of straight lines.

3.1 Estimation of rotation center of door handle

The rotation center of a door handle lies on the door handle (Figure 2). A line connecting the center point and the gripper can be obtained by knowing the position and orientation of the gripper iff the orientation of the gripper is aligned with the door handle. Therefore, two lines are obtained when the gripper rotates the door handle certain degrees. If its orientation still aligns with the door handle, the intersecting point of the two lines is the rotation center of the door handle. Therefore, it is important to use compliant motion control algorithm so that the orientation of the gripper is always aligned with the door handle. Also, the motion of the gripper should be properly controlled to rotate the door handle.

The rotation center is calculated by computing the intersecting point of the two lines. Therefore, the estimation algorithm is not affected by the gripper's slip along the door handle. In fact, since the rotation center is estimated and the position of the gripper is known, it can also be identified whether the gripper is slipping or not.

The first line gets created right after the gripper grasps onto the door handle, and the next line gets created after the end-effector control point moves a certain distance (1mm in our experiments) away from the previous position. For a straight line to be computed, there are two variables that need to be known: slope and shift. The slope is calculated by obtaining the Euler parameter: angle and axis. In Figure 2, the door handle is on x-z plane and rotates along rotation of y-axis. Therefore, the equation of straight line becomes $z = mx + n$, where m and n are the slope and shift of the straight line, respectively. In order to calculate the slope(m), the initial and current rotation matrices of the gripper are used to compute the rotation matrix.

$$ {}^1_2R = {}^0_2R\, {}^0_1R^+ \tag{1} $$

where, ${}^0_1R$, ${}^0_2R$, ${}^1_2R$ are initial, current, and relative rotation matrix, respectively. From this relative rotation matrix, Euler parameters can be computed to obtain the rotation axis direction vector, $\hat{k}$, and rotation angle, θ. As mentioned above, the door handle is on two dimension x-z plane and rotates about y axis. Since only the y-axis rotation is controlled to be compliant, $\hat{k}$ becomes approximately y-direction during the motion.

As the door handle rotates, θ_i is to be computed whenever the gripper moves a certain distance further, where the sub-script, i, denotes ith computed angle. After obtaining each θ_i, the slope of each straight line becomes

$$m_i = \tan\theta_i \tag{2}$$

Now the shift, n, is easily calculated since the gripper point and the slope are known. With this procedure, the straight lines get created when the end effector moves a certain distance away from the previous position.

The most simple algorithm would be to calculate the intersection point using only two straight lines. However, the rotation center cannot be estimated very well by only two straight lines since the gripper is not perfectly compliant with the gripper in terms of the orientation. Therefore, the computed point becomes quite noisy. To reduce this phenomenon, the most recent 10 straight lines are used in this paper.

$$\begin{pmatrix} \hat{x}_c \\ \hat{z}_c \end{pmatrix} = \begin{pmatrix} m_1 & 1 \\ m_2 & 1 \\ \vdots & \vdots \\ m_{10} & 1 \end{pmatrix}^{+} \times \begin{pmatrix} n_1 \\ n_2 \\ \vdots \\ n_{10} \end{pmatrix} \tag{3}$$

where, $\hat{x}_c$, $\hat{z}_c$, m_i, n_i are the estimated x and z coordinates of the rotation center of the door handle rotation, slope, and shift, respectively. One of the biggest merits of this estimation method is that slip of the gripper on the door handle does not affect estimation.

3.2 Control Strategy

The equations of motion of a manipulator in operational space is [13]

$$\Lambda(x)\ddot{x} + \mu(x,\dot{x}) + p(x) = F \tag{4}$$

where x denotes the orientation and position of the end-effector, and $\Lambda(x)$, $\mu(x,\dot{x})$, and $p(x)$ are the inertia matrix, a vector of Coriolis/centrifugal forces, and a vector of gravity forces in the operational space, respectively. The control force, F, in (4), can be composed to provide a decoupled control structure:

$$F = \hat{\Lambda}(x)f^* + \hat{\mu}(x,\dot{x}) + \hat{p}(x) \tag{5}$$

where $\hat{\Lambda}(x)$, $\hat{\mu}(x,\dot{x})$, and $\hat{p}$ present the estimates of $\Lambda(x)$, $\mu(x,\dot{x})$, and $p(x)$. The term, f^*, is the input of the unit-mass system, which provides the decoupled control for each direction of the end-effector, i.e. the gripper in the paper. Using a PD controller, f^* is composed as

$$f^* = k_p(x - x_d) + k_v(\dot{x} - \dot{x}_d) \tag{6}$$

where k_p and k_v are the proportional and derivative gains, respectively. The term, x_d, denotes the desired position

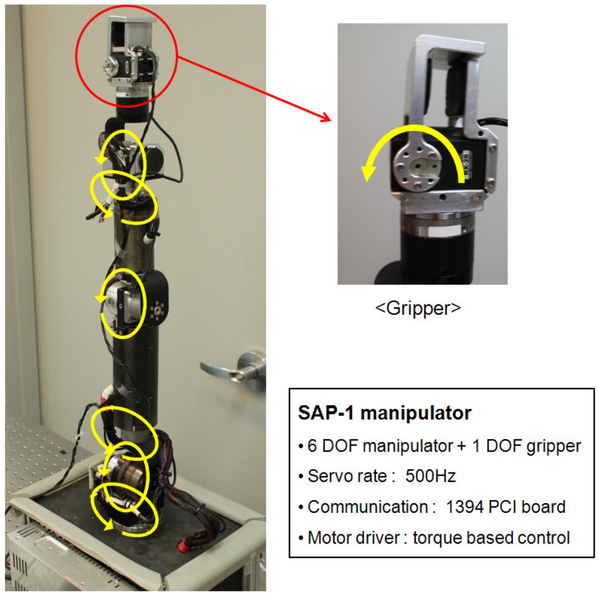


Fig. 3 6 DOF SAP-1 manipulator: Torque-based control manipulator with 6 DOF. Yellow circular arrow represents the rotational direction of each joint, and red circle is the gripper. Gripper of SAP-1 manipulator is a single joint controlled separately by CM-700 Controller.

and orientation of the gripper.[1] After composing f^* and F, the torque command to the robot is

$$\Gamma = J^T F \tag{7}$$

where Γ and J^T are the joint torque command and Jacobian transpose matrix, respectively.

Motion control in this framework is implemented by setting the PD gains and the desired trajectories for motion. First of all, the gains for rotation about y direction are set to be zero so that the gripper is compliant to the rotation of the door handle. For other directions, the gains are chosen to have approximately 6 Hz bandwidth.

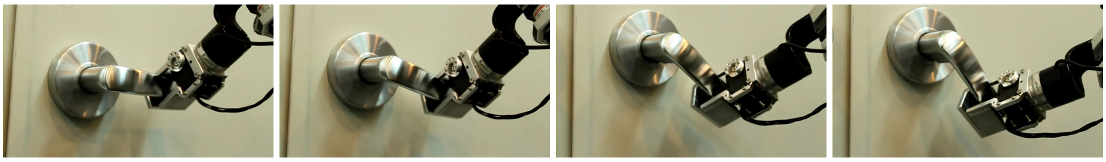
The desired y position, and the desired rotation about z axis maintains its initial configuration right after where the gripper grasp the door handle, since the manipulator is in parallel with the door handle.

The desired x_d and z_d values are composed to be a circular trajectory around the estimated rotation center of the door handle:

$$\begin{aligned} x_d &= \hat{x}_c + \hat{r}\cos(\theta_d) \\ z_d &= \hat{z}_c + \hat{r}\sin(\theta_d) \end{aligned} \tag{8}$$

where $\hat{x}_c$ and $\hat{z}_c$ are the estimated x and z coordinates of the rotation center point of the door handle, and $\hat{r}$ is the distance between the end-effector control point and estimated center point and θ_d is the desired rotation angle, which increases from initial angle to 80° to form a circular trajectory from initial configuration.

[1] The notation, x, is used for the x-coordinate of the gripper throughout the paper. However, the term, x, denotes the position and orientation of the gripper only in (4), (5), and (6).



(a) (b) (c) (d)

Fig. 4 6 DOF SAP-1 manipulator twisting the door handle: The desired trajectory is created by real-time estimation method and low-pass filter with cut off frequency of $0.1Hz$(a) Initial state when the gripper grasped onto the door handle. (b) 2 second after the initial state. (c) 4 second after the initial state. (d) Final state when the manipulator fully twisted the door handle.

4. EXPERIMENT VALIDATION

The experiment is conducted to demonstrate and validate the proposed strategy for twisting door handle under uncertainty. A physics-based realtime robot control module and programmable interface, called ROBOTICSLAB [14], is used to control the manipulator. The manipulator used in this experiment is the 6 DOF SAP-1 manipulator (see Figure 3). The SAP-1 manipulator is connected to a PC, through 1394 PCI-board and the servo rate of the controller for the manipulator is 500 Hz. The gripper on SAP-1 is controlled separately by the ROBTIS CM-700 controller.

The snapshots from the experiments are shown in Figure 4. The gripper successfully twist the door handle even though the incorrect information about the rotation center is provided. The plots from the experiment are shown in Figures 5-7.

Figure 5 shows the estimated rotation center and the desired trajectory of the gripper using the estimated rotation center. As can be seen in Figure 5, the initial rotation center point of the door handle is given 40cm away from the actual center point, in order to emulate the imperfect information about the door handle such as vision sensor error. Then, the initial given estimated door handle axis of rotation center points converge to the actual door handle axis of rotation center point as the manipulator continuously twists the door handle. This means that the realtime estimation strategy is appropriate to twist the door handle without accurately knowing the actual rotational axis center point of the door handle. Therefore, the desired trajectory generated by estimation center points is reliable to implement as desired trajectory to the manipulator.

Without accurately knowing the information of the door handle before twisting the door handle, it was successful to obtain the rotation center point of the door handle. However, due to initial door handle rotational center point location and converging process to actual center point location, the desired trajectory for the manipulator is not smooth enough to be used (see Figure 6). Therefore, low-pass filter with cutoff frequency of $0.1Hz$ is applied for the estimated desired trajectory before it is commanded to the controller.

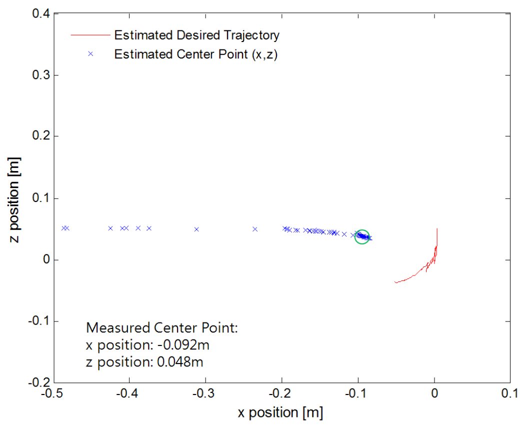


Fig. 5 Plotted result of door handle rotational axis center point and desired trajectory. Initial center point location is given (-0.492,0.5) which is 40cm away from the actual measured center point. Blue '×' marker is the estimated center point location, and the marker converges to the actual center point region where is indicated with green circle. The red graph is the result of the trajectory formulated by the the estimated center point values.

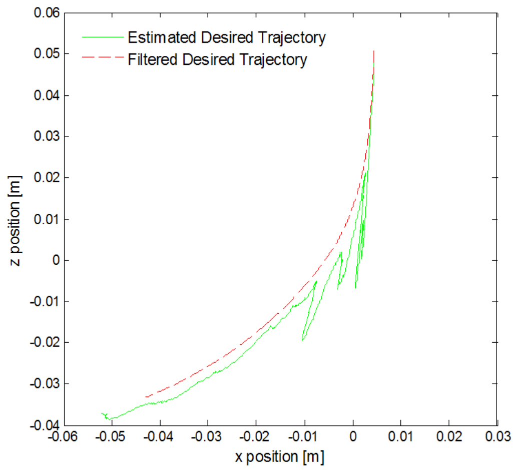


Fig. 6 Plotted result of estimated desired trajectory (green straight line) and filtered desired trajectory (red dotted line). The filtered desired trajectory is derived from estimated desired trajectory implementing low-pass filter with cut-off frequency of $0.1Hz$.

In final, Figure 7 is the plotted result of applying the filtered desired trajectory to the manipulator. The difference between the desired and actual trajectory is due to the reaction force from the door handle. It should be noted that all the plots are from the same experiment, meaning that the rotation center is being estimated while the door handle is rotated by the robot and this estimated center is used to generate the desired trajectory for the gripper simultaneously.

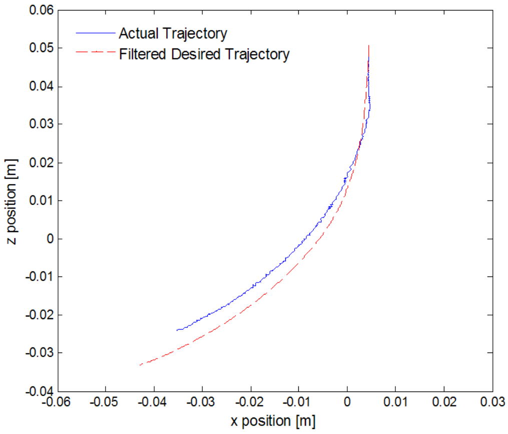


Fig. 7 Plotted result of actual trajectory (blue straight line) and filtered desired trajectory (red dotted line). The actual trajectory follows the filtered desired trajectory yet not completely. This is due to reaction force from the door handle.

5. CONCLUSION

A strategy for twisting door handle under uncertainty is proposed in this paper. Twisting door handle is one sub task of door opening performance. Twisting the door handle could be a simple task when accurate information is provided. However, the information about the door handle would often not be available or accurate enough for twisting a door handle. Therefore, a proper control and estimation strategy are required for twisting door handle.

The proposed approach is validated by conducting experiments using a 6 DOF manipulator. The results successfully show the efficiency and performance of the proposed control and estimation algorithm. We are expecting to apply similar strategies on other constrained object or environment to identify and control them simultaneously.

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