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Manipulating a multi-DOF robot manipulator for tasks in home-like environments

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Abstract: As more robots are expected to enter the families to provide assistance soon, many challenging problems shall emerge, when facing the uncertain and varying environments, rather than the organized environments in factories. To date, robots still demand human's assistance when working in home-like environments. To enhance their usefulness, one issue of much interest is how we can effectively operate them for task execution. If not for detailed analysis and program coding, one appealing alternate is to provide a kind of manipulative system for the user to manipulate the robot naturally and efficiently. That motivates us to develop a dextrous manipulation system for multi-DOF robot manipulators based on using the 6-DOF force-reflection joystick. To demonstrate its effectiveness, the developed manipulation system is utilized to govern the robot manipulator for the tasks of water pouring and screw fastening.

Keywords: Manipulation system, Haptic device, Virtual tool, Home-like environment.

1 INTRODUCTION

In the near future, more robots may enter the families to provide assistance. As expected, many challenging problems shall emerge in dealing with the uncertain and varying environments, rather than the organized environments in factories [4]. Up to now, robots still demand human's assistance when working in home-like environments. To enhance their usefulness, one issue of much interest is how we can effectively operate them for task execution. If we are not going to take the load of detailed task analysis and program coding, one alternate is to let the user manipulate the robot via a proper means directly. In other words, an effective manipulation system should be provided for the user to achieve natural and efficient robot governing. As traditional manipulative devices, like teach box, mouse, keyboard, and joystick, may not serve the purpose, we propose developing a dextrous manipulation system for multi-DOF robot manipulators based on using the haptic device.

As the manipulative device, we adopt the 6-DOF force-reflection joystick for the proposed manipulation system, which supports mutual interaction, involves both position and force information, and has the merit in its simplicity and generality. In this manipulation system, we design virtual motion constraints, which are based on the concept of virtual mechanisms and virtual fixtures previously proposed [1,3,7], to confine the movement of the manipulative device in the 3D working space, according to the status of the robot manipulator and task progress. In other words, the virtual motion constraints are designed (i) to help the user recognize the spatial deviation between her/his desired position and the end-effector via a haptic clue, and (ii) to guide her/his movement according to task requirements via some virtual tools. For instance, a virtual ruler can be used to help the user to move the robot along a straight line fast and precisely. The proposed manipulation system thus provides two kinds of virtual motion constraints to assist the user in an interactive and real-time manner. First, a virtual spring is installed between the user and robot manipulator to enhance a virtual linkage between them. In addition, a 3D graphical environment is also implemented to foster the virtual linkage in a visual way. Second, four basic types of virtual tools (point, line, plane, and fixed-rotating-axis) are furnished according to the user's demand on site, but not in a predefined environment or predicted way [2,5]. For demonstration, the manipulation system is utilized to govern the robot manipulator to conduct two kinds of tasks: pour the water between tubes and fasten the screw, both of which demand delicate maneuver. Satisfactory experimental results verify the effectiveness of the proposed manipulation system.

2 PROPOSED MANIPULATION SYSTEM

Fig. 1 illustrates the two major goals of the proposed manipulation system for a multi-DOF manipulator: (i) letting the user feel like she/he is manipulating the robot on site directly when teleoperating the task, and (ii) providing a set of virtual tools that guide the hand movement of the user. Its system block diagram is shown in Fig. 1b, which consists of mainly a 6-DOF haptic device, a virtual linkage, and virtual tools. Via the haptic device, the user sends in the commands, which may be refined by the virtual tools, to govern

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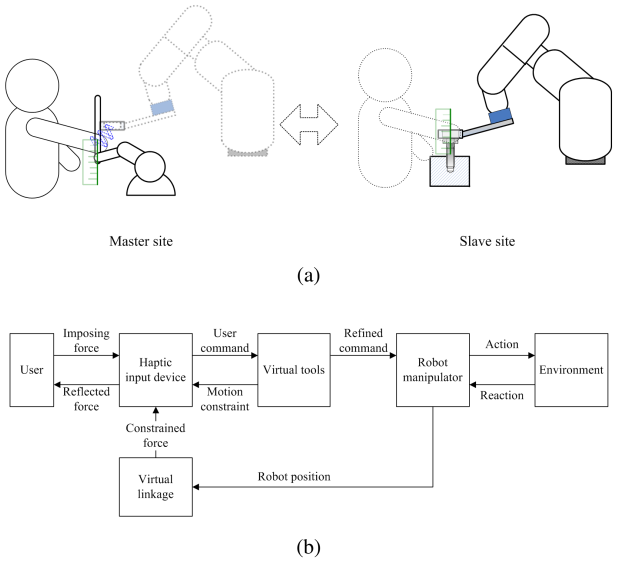

Fig. 1: Proposed manipulation system for a multi-DOF robot manipulator: (a) conceptual diagram and (b) system block diagram.

Fig. 2: The user applies the proposed system to manipulate the real robot manipulator via a haptic input device and 3D graphical environment.

the robot manipulator in the slave site to perform the task in a home-like environment. As the feedback, the robot position, via the virtual linkage and then the haptic device, becomes the reflected force, which is sent back to the user for following manipulation. Meanwhile, the system utilizes the virtual tools to furnish motion constraints for guidance. Based on the descriptions above, the success of the proposed manipulation system mainly depends on proper design of the virtual linkage and virtual tools. The former establishes the human-robot connection for natural and effective manipulation, and the latter provides proper assisting motion constraints along with the progress of task execution.

With the proposed virtual linkage, we intend to create better interaction between the user and robot manipulator, so that the user can perform the manipulation naturally and effectively. Fig. 2 shows a scene in which the user applies the proposed manipulation system to manipulate the real robot manipulator via a haptic input device and 3D graphical environment, which renders the user the linkage status between the master and slave devices in visual way. For the haptic counterpart, we intend to let the user feel like her/his hand holding on the end-effector of the robot manipulator directly. Although direct reflection of the environmental force to the master may yield the user a more realistic feeling, the induced master motion may make system unstable [6]. Therefore, the proposed linkage haptic cue is used to hint the position deviation between the robot manipulator and the desired command, reminding the user that the robot manipulator cannot catch up with the command, in an intuitive and efficient way compared with that provided by the visual information. To achieve this, we use a simple spring model to generate the constrained force via the force-reflection joystick, serving as a virtual spring that bonds the joystick with the robot manipulator. This constrained force $\mathbf{f}_s(n)$ is formulated as

$$\mathbf{f}_s(n) = K_s(\mathbf{p}_s(n) - \mathbf{p}_u(n)), \quad (1)$$

where K_s stands for the stiffness of the virtual spring, and $\mathbf{p}_s(n)$ and $\mathbf{p}_u(n)$ the position of the end-effector and force-reflection joystick, respectively, both with respect to the coordinate system of the master.

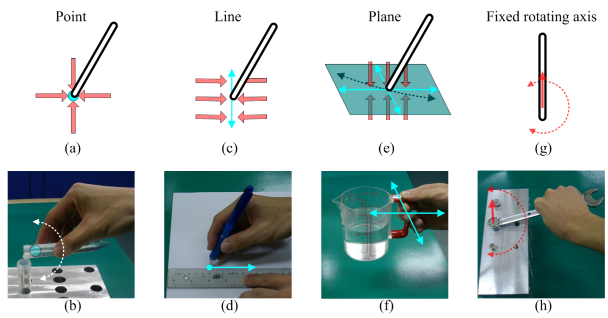

Fig. 3: Proposed virtual tools and their possible applications: (a)-(b) point, (c)-(d) line, (e)-(f) plane, and (g)-(h) fixed-rotating-axis.

To tackle common operations in home-like environments, we design three types of position tools: point, line, and plane, and one type of orientation tool: fixed-rotating-axis. Fig. 3 shows these four virtual tools and their possible applications. The position tools can let the haptic device only move on a point, a line, or a plane, for instance, a point tool for the

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water pouring task. The orientation tool can let the haptic device maintain a fixed rotating axis for rotation, such as for the screw fastening task. Details of their implementation will be in our following paper.

3 SYSTEM IMPLEMENTATION

As shown in Fig. 2, the proposed manipulation system consists of a 6-DOF Mitsubishi RV-2A robot manipulator, with a mounted end-effector, such as a box-end wrench or gripper, a SensAble Phantom Omni 6-DOF joystick with 3-DOF force feedback, and a personal computer (Intel Core Duo E8400 CPU and 2 GB RAM) for constructing the 3D graphical environment for rendering the virtual robot and virtual tools, in addition to the computation of the haptic feedbacks for both the virtual linkage and virtual tools. To satisfy the requirements from various devices, we use three threads to deal with the haptic data (about 1 kHz), visual data (about 60 Hz), and manipulator control data (about 141 Hz). To match up the workspaces between the haptic device and robot manipulator, the length ratio between these two coordinates is set to be 1:2.

4 EXPERIMENTS

To demonstrate its effectiveness, the proposed manipulation system was utilized to govern the robot manipulator to conduct two kinds of tasks: pour the water between tubes and fasten the screw, both of which demand delicate maneuver. For each experiment, there were two operation modes: with the help of both virtual tools and virtual linkage (mode V) and without those (mode NV). To alleviate the learning effect, eight subjects were first invited to conduct the first experiment, and then another seven subjects for the second one. Moreover, the order of these two operation modes was randomly arranged for the subject. Each subject was asked to achieve two successful trials for each mode. Most of them had no experience in manipulating the robot manipulator using the haptic input device before. Thus, before conducting the trial for each mode, the subject practiced several times to be familiar with the manipulation system.

Fig. 4 shows the setup of the first experiment, in which the robot manipulator was governed to grasp the tube vertically up, which was initially put in the hole on the right rack, and then horizontally moved it to pour the water inside into the tube on the left, and finally put it back to the original location in a reversal sequence. A successful trial should transfer at least 90% of the water. In responding to the operations, mode V provides two line tools for vertical up and down, two plane tools for horizontal leftward and rightward, and one point tool for water-pouring rotation. The experimental results show that, the medians of the execution time for the two modes (NV: 59.2 s and V: 50.0 s), indicating that the virtual tools helped to reduce about 9.2 s (15.5 %); the medians of the traveling path for the two modes (NV: 817 mm and V: 721 mm), indicating a reduction of about 96 mm (11.8 %). Fig. 5 shows the robot trajectories for a specific user as an example. In Fig. 5a, the virtual tools led to quite straight movements in up and down, more smooth movements in a horizontal plane during leftward and rightward, and steady rotation in water pouring. Most of subjects reported that the bonding forces from the virtual linkage and virtual tools did help to maintain stable movements.

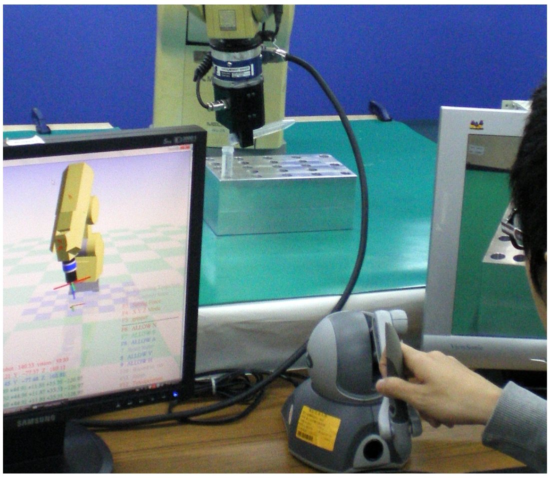
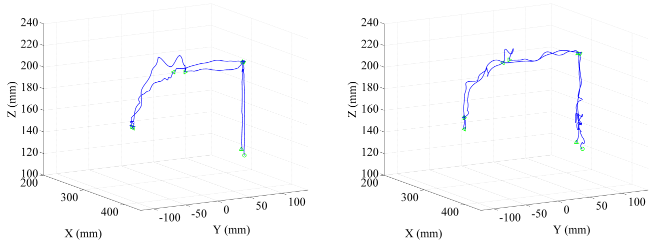


Fig. 4: Water pouring task.



(a) (b)

Fig. 5: Robot trajectories of water pouring for a user as an example: (a) with the help of virtual tools and (b) without the help.

The setup for the second experiment is shown in Fig. 2. The robot manipulator was governed to fasten a hexagonal screw via a box-end wrench. The procedure is as follows:

1. Place the box-end wrench over the screw head and pose a proper rotating axis for next step.
2. Rotate the wrench clockwise certain angle to fasten the screw and at the same time keep the rotating axis fixed.
3. Release the wrench from the screw and then rotate the wrench counter-clockwise certain angle.

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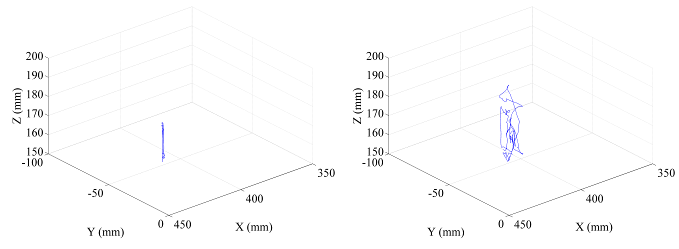
4. Repeat the steps above until the screw is fastened.

In responding to these steps, the subject can utilize two kinds of virtual tools to assist in the manipulation, described as follows:

- The line tool is used to assist in the straight motion along with the rotating axis, which helps to place the wrench over the screw.

- The orientation tool is used to maintain a fixed rotating axis to prevent the user from inaccurate manipulation.



(a) (b)

Fig. 6: Robot trajectories of screw fastening for a user as an example: (a) with the help of virtual tools and (b) without the help.

The experimental results show that, the medians of the execution time for the two modes (NV: 33.24 s and V: 25.06 s), indicating the virtual tools helped to reduce about 8.18 s (24.6 %); the medians of the traveling path for the two modes (NV: 216.5 mm and V: 119.6 mm), indicating a reduction of about 96.9 mm (44.8 %). Fig. 6 shows the robot trajectories for a specific user as an example. With the help of the proposed virtual tools, the trajectories in Fig. 6a were straight and more close together, compared with those in Fig. 6b. Furthermore, most of subjects reported that with the help of virtual tools they could place the wrench over the screw and stably fasten it more fast and precisely.

5 CONCLUSION

In this paper, we have proposed an effective manipulation system for multi-DOF robot manipulators based on virtual linkage and virtual tools. The virtual linkage enhances the connection between the user and robot manipulator, and virtual tools are helpful in dealing with the requirements from various tasks. We have applied the proposed manipulation system to conduct two different kinds of tasks, both of which demand delicate maneuver. Satisfactory experimental results have verified its effectiveness. In future works, we plan to enhance the proposed manipulation system, so that it can be applied for more versatile tasks in home-like environments.

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