Linkage of Virtual Object and Physical Object
for Teaching to Caregiver-Robot

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Abstract

To support a bedridden person, we propose a novel teaching method for a caregiving robot to manipulate a physical object in a real world. User's instruction can be intuitively transmitted to the robot by the "drag-and-drop" operation between a virtual object in a PC display and the physical object. The validity of the proposed method is experimentally confirmed using a fetching task as an example.

Categories and Subject Descriptors (according to ACM CCS): I.3.m [Miscellaneous]:

1. Background

To support a bedridden person, we have been studying interfaces that can flexibly convey information to a caregiver about what the bedridden person wants to do with a real object. The interfaces work by seamlessly indicating the virtual object on the computer screen and the real object in the real world [NAI*14]. Specifically, we have established a method to seamlessly indicate objects in the real and virtual worlds by using the input interface signal from a mouse through normal cursor operations on the PC display and by physically driving a pan-tilt actuator equipped with a laser pointer that is illuminated. Combining all of the above, we have proposed a concept of real-world drag and drop and a method to use GUI-like operations for intuitively transmitting instructions about the physical manipulation of a real-world object to a caregiver. In this paper, in order to extend these methods to enable communication with a caregiver *robot*, we propose a care support robot system for moving real objects and we experimentally study the system's effectiveness.

2. Caregiver robot system proposal

Here we define *real-world clicking* as the acquisition, triggered by a click action, of the three-dimensional position of the object on which the laser beam is irradiated. In our proposed method, the three-dimensional position of the laser spot is determined through angle measurement using encoders in the pan-tilt actuator and measurement of the laser beam length based on the time-of–flight (TOF) principle.

Coordinate systems of hardware components of the proposed system are shown in Figure 1, where forward-kinematics and inverse-kinematics of the robot arm shall be known as equation (1) and (2).

$$\mathbf{DK}(\boldsymbol{\theta}) = {}^{R}\boldsymbol{T}_{H} = \begin{pmatrix} {}^{R}\boldsymbol{R}_{H}(\boldsymbol{\theta}) & {}^{R}\boldsymbol{p}_{H}(\boldsymbol{\theta}) \\ \mathbf{0} & 1 \end{pmatrix} \qquad (1)$$

$$\boldsymbol{\theta} = \mathbf{IK}({}^{R}\boldsymbol{R}_{H}, {}^{R}\boldsymbol{p}_{H}) \qquad (2)$$
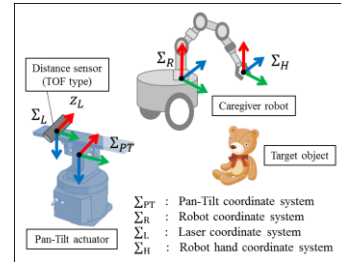
Figure 1: Coordinate systems

Here, $\boldsymbol{\theta}$ is an angle vector of each joint of the robot arm, ${}^{R}\boldsymbol{R}_{H}$ is a rotation matrix that express an orientation of the robot-hand with respect to $\sum_{R}$, ${}^{R}\boldsymbol{p}_{H}$ is a vector that express a position of the robot-hand. Then the control algorithm for the robot to grasp an object is proposed below.

i. **Calculation of ${}^{PT}\boldsymbol{T}_{L}$: homogeneous transformation matrix from $\sum_{PT}$ to $\sum_{L}$**

$\sum_{PT}$ is fixed on the stator of the pan-tilt actuator and $\sum_{L}$ is fixed on the rotor, so ${}^{PT}\boldsymbol{T}_{L}$ is expressed as equation (3).

$$ {}^{PT}\boldsymbol{T}_{L} = \mathbf{DK}_{PT}(\boldsymbol{\theta}_{PT}) \qquad (3)$$

where, $\mathbf{DK}_{PT}$ is forward-kinematics of the pan-tilt actuator. $\boldsymbol{\theta}_{PT}$ is a vector composed of pan-tilt angle.

ii. **Calculation of ${}^{PT}\boldsymbol{r}$: target object's position with respect to $\sum_{PT}$**

${}^{PT}\boldsymbol{r}$ is calculated as equation (4),

$$ {}^{PT}\boldsymbol{r} = {}^{PT}\boldsymbol{T}_{L} \cdot {}^{L}\boldsymbol{r} \qquad (4)$$

where, ${}^{L}\boldsymbol{r} = (0,0,z_r)^{\mathrm{T}}$ is a 3D coordinate value of the laser spot on the target object with respect to $\sum_{L}$, and z_r is a sensing data measured by the laser distance sensor.

iii. **Locomotion control of the caregiver robot**

${}^{PT}\boldsymbol{T}_{R}$ **:** the posture of the caregiver robot with respect to $\sum_{PT}$ is obtained from the mobile robot odometry. Then, the locomotion control is executed until the equation (5) will be satisfied.

$$_{\max}|\,^{R}\boldsymbol{p}_{H}(\boldsymbol{\theta})| > |\,^{PT}\boldsymbol{r} - \,^{PT}\boldsymbol{p}_{R}| \qquad (5)$$

where, $_{\max}|\,^{R}\boldsymbol{p}_{H}(\boldsymbol{\theta})|$ is maximal distance between Σ_{R} and Σ_{H}.

iv. **Calculation of ^{R}r: target object's position with respect to Σ_{R}**

^{R}r is calculated as equation (6).

$$^{R}\boldsymbol{r} = \,^{PT}\boldsymbol{T}_{R}^{-1} \cdot \,^{PT}\boldsymbol{r} \qquad (6)$$

v. **Calculation of θ**

Each joint angle of the robot arm is controlled with the reference angle θ which is calculated as equation (7).

$$\boldsymbol{\theta} = \mathbf{IK}(\,^{R}\boldsymbol{R}_{H},\,^{R}\boldsymbol{r}) \qquad (7)$$

where, $^{R}\boldsymbol{R}_{H}$ is manually determined by a user, watching the target object and the hand

vi. The target object is grasped by the robot hand.

3. Prototype system and demonstration experiments

3.1 Prototype system overview

Figure 2 shows our prototype system. During real-world pointing, the image obtained by the camera is displayed in the observation window as shown in Figure 3. In addition, a home icon symbolizing the position of the user is placed in the PC screen. Instructions on the manipulation of a real object are given by the user and transmitted to the system, letting the virtual object interact with the real-world object.

3.2 Demonstration experiments

Demonstration experiments were conducted as described below.

1. The user performs a pointing operation in the real world and views the object to be grasped through an observation window.

2. After indicating the physical object with the pointer in the real world, the user real-world clicks the position where the robot should grasp the object and drags and drops it to the home icon on the PC screen.

3. The robot automatically moves to the location clicked in the real world, grasps the object with the robot hand, and carries it to the location of the user.

Panels (1) to (4) in Figure 4 show the respective images in chronological order. Panel (1) shows the state just after the normal PC operation is switched to real-world pointing. The actuator-mounted laser pointer continues pointing, as if th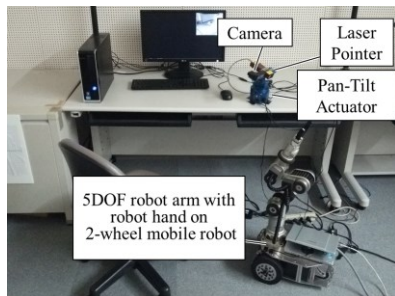e cursor had jumped off of the PC display into the real world. In (2), the target object is illuminated by the laser beam. In (3), the robot grasps the object. In (4), the robot is fetching the object to the user.

The experimental protocol has been instructed to 20 healthy and non-expert subjects by showing the demonstration of the operation. As a result of the experiments, 18 users could successfully execute the robot operation. We consider that the reason why the success rate was considerably high for the unfamiliar users is as follows; our proposed drag-and-drop operation between PC and real world was intuitive and easy because it really resembles the familiar GUI-based drag-and-drop operation inside the PC screen with a mouse. Therefore we can verify the basic effectiveness of the proposed technique.

4. Conclusion

For supporting nursing care recipients who are confined to bed, we proposed and demonstrated a method in which the instructions on the manipulation of a real object could be intuitively transmitted to a care support robot by connecting the real object in the real world with a virtual object in the computer. This was accomplished through a drag-and-drop operation for linking the real and virtual objects.

References

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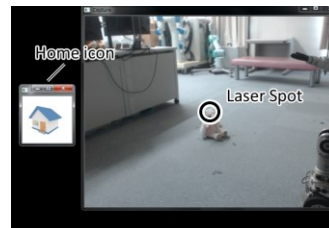

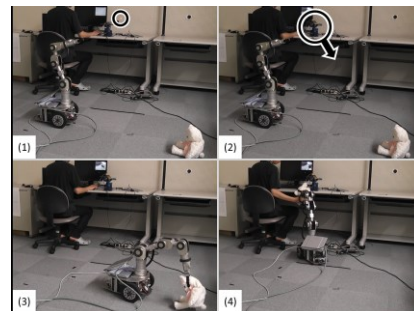**Figure 3:** Camera image on the user's display

Figure 4: The motion sequence of the robot to fetch a target object

Figure 2: Overview of the experimental system