Robot Mobile Control Technology Using Robot Arm as Haptic Interface

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Abstract: This paper proposed the implementation of haptic-based robot which is following human by using fundamental sensors on robot arms without additional sensors. A Robot arm has 6 DOF (6 angle detection devices) to operate like human arm. Robot follows human by interacting with robot arm(s) and human hand(s), as human follows hand(s)

Key-Words: Intelligent robot, Human robot interaction, Following robot, Mobile robot, Haptic

1 Introduction

Recently, various researches are carried out on interaction and development between human and robot, and now intellectualization of robot is accelerated based on industrial robot technology [1][2]. A number of intelligent robot researches are attempting to apply to various fields such as syncope, medical treatment, art, plaything and helper. In order to perform various functions, intelligent robot must possess abilities that can cope with unpredictable environments. However, current abilities of robot with simple working and following fixed programs have much limitation. To solve these problems, developing robot intelligence is much required. Especially, it is very important to develop technologies related with interaction and understanding user's action and feelings.

For effective interaction between human and robot, it is helpful to use the information based on human experience and knowledge [3]-[5]. Therefore, many researches are recently performed on human-robot interface based on vision, speech, haptic, eye-gaze, and gesture. Especially, haptic interface has many advantages that human can order robot system through human actions and robot can present strength information to human through feedback from robot. Therefore, users can feel system’s situation immediately and realistically [6][7].

Human feels haptic through two principal routes. One is called kinesthetic that feels through muscle sense. The other is called tactile that feels through direct touch. So, haptic interface technology has been developed through these two routes.

The humanoid robot used in this paper, “RoMAN” has 6 joints in its robot arm. This robot arm can be used as muscular sensation haptic interface, since position control, speed control, and force control are available. This paper proposes the haptic interface technology using robot arm. By touching and moving the robot arm, it controls robot motion (called mobile), and it can realize humanoid robot that follows human. This paper also explains hardware architecture of “RoMAN” and its haptic-based motion control method.

2 RoMAN

We used life-size humanoid robot “RoMAN”. It consists of five modules imitating human body function. They are neck module, arm module, hand module, torso module, and mobile module, as shown in Fig. 1. RoMANs arms are designed like two human arms, and it can control position, speed, and force.[8]

RoMAN’s arms consists of 6 pivot joints, and all axes have DC servo-motor. Communication between each axis are performed through CAN communication. As shown in Fig. 2, each turning coordinate system consists of 6 axis (flexion/extension of shoulder, abduction/adduction of shoulder, medial/ lateral rotation of shoulder, elbow, medial/lateral rotation of wrist, flexion/extension of wrist), and their driving ranges are shown in Table 1. Wheel-based mobile module consists of two drive wheels, two assistance wheels, power supply and decoder. Hand and neck modules use RS-485 communication.

Fig. 1 Humanoid robot “RoMAN”

2.1 Forward Kinematics
RoMAN’s arm consists of 6 pivot joints. Coordinate system of joint 3 and joint 4 do not satisfy D-H rules. In this paper, relational expression of joint 3 and joint 4 are derived using general coordinate system transformation matrix. For other joints, homogeneous transformation matrix is derived according to modified D-H rules.

Table 1 expresses parameter values of links by modified D-H rule. Because each joint is pivot, \( \theta_j \) is a variable and the others are constants.

<table>
<thead>
<tr>
<th>Link</th>
<th>( \alpha_i, -1 )</th>
<th>( a_i, -1 )</th>
<th>( d_i )</th>
<th>( \theta_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>( \theta_1 )</td>
</tr>
<tr>
<td>2</td>
<td>-90°</td>
<td>0</td>
<td>0</td>
<td>( \theta_2 )</td>
</tr>
<tr>
<td>3</td>
<td>90°</td>
<td>0</td>
<td>( d_3 )</td>
<td>( \theta_3 )</td>
</tr>
<tr>
<td>4</td>
<td>-90°</td>
<td>0</td>
<td>0</td>
<td>( \theta_4 )</td>
</tr>
<tr>
<td>5</td>
<td>90°</td>
<td>( d_5 )</td>
<td>0</td>
<td>( \theta_5 )</td>
</tr>
<tr>
<td>6</td>
<td>-90°</td>
<td>0</td>
<td>0</td>
<td>( \theta_6 )</td>
</tr>
</tbody>
</table>

Their homogeneous transformation matrix is derived as Equations (1)-(7).

\[
\begin{align*}
&T = \begin{bmatrix} c_1 & -s_1 & 0 & 0 \\ s_1 & c_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} , \\
&T = \begin{bmatrix} c_2 & -s_2 & 0 & 0 \\ s_2 & c_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} , \\
&T = \begin{bmatrix} c_3 & -s_3 & 0 & 0 \\ s_3 & c_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} , \\
&T = \begin{bmatrix} c_4 & -s_4 & 0 & 0 \\ s_4 & c_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} , \\
&T = \begin{bmatrix} c_5 & -s_5 & 0 & 0 \\ s_5 & c_5 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} , \\
&T = \begin{bmatrix} c_6 & -s_6 & 0 & 0 \\ s_6 & c_6 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} .
\end{align*}
\]

3 Robot That Follows Human

RoMAN was designed to control mobile using outside joystick. In this paper, we propose haptic interface to control mobile by grabbing and pulling robot arm as a human guides other human by grabbing and pulling his/her arm.

When human guides a robot to his/her intended direction, some force is applied to its arm, as shown in Fig. 3. This force has same direction with his/her intended direction. This force changes position of robot arm. Robot arm keeps its position until stronger force or force of other direction is applied. Since human’s intended direction is closely related with the position of robot arm, mobile control is possible through recognizing the position of robot arm only without additional sensors.

3.1 One-hand Mode

In this paper, the experiment shown in Fig. 4 was carried out to find correlation between angle changes of robot arm and human’s relative location with respect to robot’s location. In the experiment, human’s intended direction was changed by every 10 degrees, and the angles of each axis in robot arm were measured. Axis 5 and 6 are in wrist part, and they were fixed in the experiment since they are seldom related to human’s intended direction. So only axis 1–4 were measured in the experimented. The angle change of axis was calculated by counting rotating number of motor in the axis.

Fig. 5 shows the result of “One-Hand Mode” where x indicates the intended direction and y indicates the angles of axis. As shown in Fig. 5, the change of intended direction is mainly related to axis 2 and axis 4 Axis. This
relation can be approximated to linear function. Axis 1 and axis 4 are also changed, but the relationship seems negligible.

From the experimental results, we derived the conditions of axis angles in 4 movement control modes, i.e. forward, right turn, left turn, stop. These conditions were shown in Table 2. In Fig. 5, Axis 2 and Axis 3 have similar characteristics. Their angles have positive values when intended direction is left and negative values when right. Therefore, we used (axis 2 + axis 3) to determine left and right turning. We defined stopping and forwarding modes as lifting and putting down robot arm, respectively. Therefore, angle of axis 1 is also used in mobile control. Thresholds of angles in each control mode are optimized by experiments to perform stable movement.

### 3.2 Two-hand Mode

Fig. 6 shows the experiment of “Two-Hand Mode” in a similar way with “One-Hand Mode”. In this case, angle variation is opposite to the intended direction. Angles of left and right arms are exactly opposite due to the symmetry of both arms.

Fig. 7 shows the result of “Two-Hand Mode” where x indicates the intended direction and y indicates the angles of axis. Note that angles of axis 2 and axis 3 are opposite in left and right arms. Like one-hand mode, axis 1 and axis 4 are also changed, but the relationship seems negligible.

Similarly with one-hand mode, we derived the conditions of axis angles in 4 movement control modes, as shown in Table 3. L1–L3 and R1–R3 denote axis 1–3 of left and right arms, respectively. We used \((L2 + L3) – (R2 + R3)\) to determine left and right turning. We defined stopping mode as folding, unfolding, or putting down robot arm. Also we define forwarding mode as lifting robot arm. Therefore, angle of axis 1 is also used in mobile control.

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**Table 2 Mobile Control and Angle Range of One-Hand Mode**

<table>
<thead>
<tr>
<th>Control Mode</th>
<th>Angle Range(°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop</td>
<td>(1\text{Axis} \leq 30)</td>
</tr>
<tr>
<td>Forward</td>
<td>([30 &lt; 1\text{Axis} \leq 90] &amp;&amp; {-15 \leq (2\text{Axis} + 3\text{Axis}) \leq 15})</td>
</tr>
<tr>
<td>Left Turn</td>
<td>([30 &lt; 1\text{Axis} \leq 90] &amp;&amp; {(2\text{Axis} + 3\text{Axis}) &lt; -15})</td>
</tr>
<tr>
<td>Right Turn</td>
<td>([30 &lt; 1\text{Axis} \leq 90] &amp;&amp; {15 &lt; (2\text{Axis} + 3\text{Axis})})</td>
</tr>
</tbody>
</table>

**Table 3 Mobile Control and Angle Range of Two-Hand Mode**

<table>
<thead>
<tr>
<th>Control Mode</th>
<th>Angle Range(°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop</td>
<td>([L1\text{Axis} \leq 30] &amp;&amp; [R1\text{Axis} \leq 30] &amp;&amp; [{(L2\text{Axis} + L3\text{Axis} + R2\text{Axis} + R3\text{Axis}) &gt; 50} &amp;&amp; [{(L2\text{Axis} + L3\text{Axis} + R2\text{Axis} + R3\text{Axis}) \leq -30}])</td>
</tr>
</tbody>
</table>

### 4 Implementation

Fig. 8 shows the flowchart of the combined control mode determination for one-hand mode and two-hand mode. Fig. 9 shows the RoMAN mobile control program. It is loaded to SBC (Single Board Computer) embedded inside RoMAN, and it enables mobile control without external controller. Fig. 10 shows the photograph of robot following human in indoor environment.

### 5 Conclusions

This paper proposes the haptic interface technology using robot arm and its haptic-based motion control method. By touching and moving the robot arm, it controls robot motion, and it can realize humanoid robot that follows human.

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#### References


