A Mobile Robot Operation with Instruction of Neck Movement using Laser Pointer

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Abstract: A human-robot system in which a mobile robot follows the movement of the laser spot projected on the floor by the laser pointer attached at the human head is considered. Human gives instruction of desired movement to the omni-directional mobile robot by rotating his or her head. The mobile robot can realize intended movement by following the movement of the laser spot on the floor. By projecting an instructive point to be followed by the mobile robot, the user can clearly recognize the relation between the direction being faced and the desired position of the mobile robot. In addition, the user can convey a motion trajectory to the mobile robot continuously. Kansei transfer function is introduced between the instruction movement of the laser spot and following motion of the robot. In addition, three modes, stopping mode, following mode, and autonomous motion mode to the target, are considered. The effectiveness of the proposed system was discussed experimentally, and confirmed by the smooth trajectory of the following motion of the mobile robot and good psychological evaluations.

Keywords: Human-Robot System, Instruction with Movement of Neck, Kansei Transfer Function, Three Modes

1. INTRODUCTION

With the rapid progression of an aging society in Japan, various efforts have been made concerning the use of robots to serve as functional substitute caregivers for the physically disabled and to aid in the nursing care of the elderly in medical and social welfare. The need for robots that can support the rehabilitation of or provide daily life support to the elderly and the handicapped has been emphasized [1]. Against this background, research has been conducted into robots moving in response to human instructions. For example, Aizawa et al. [2] constructed a daily life-support robot system in which a human gives instructions to a robot in response to visual information received from cameras mounted on the robot. Takahashi and Hasegawa [3] proposed a human interface of an eating assist robot developed in order to enable people with severe disability to gain independence in eating using PC display with head pointing device. Adachi et al. [4] proposed a system that supports operation of an electric wheelchair based on the eye movement of the wheelchair-user to reduce the burden of operation.

In this research, we focus on a human-robot interface in which a person instructs a mobile robot to move by rotating her or his head, so that even a person who has a speech impairment or has trouble moving an upper limb can use it. For this interface to be intuitively user-friendly, a laser pointer is attached to the user’s head and the laser beam is projected onto the floor to serve as an instruction point for a mobile robot. The mobile robot then follows the movement of the projected laser point on the floor. By using the laser pointer, it is expected that the user will be able to understand the relation between the direction the user is facing and the instruction point for the mobile robot, which will make the user feel that the system is easy to use.

As example applications for this system, a robot could move something for the user; or could conduct simple tasks at a remote destination within the same structure, such as a room in a house. It will take some time for a robot supporting daily life in close proximity to a human like this to be accepted by the public, despite recent research activities. That is to say, the confidence level of the average person in autonomous performance by a robot is not very high at the present time, especially for people who are not familiar with robots. When a robot performs autonomous movement in the same environment as a human, the person cannot predict accurately the motion trajectory of the robot, which makes the person feel anxious or worried. In contrast, if a robot moves following human instruction, the generated movement reflects human motion characteristics, which is acceptable to human psychology [5].

Takahashi et al. [6] reported a system in which a user gives instructions to a mobile robot by using a laser pointer held in the hand. In their report, the laser pointer is used for indicating the target to the mobile robot when the trajectory of the robot from its current position to the target position cannot be determined by the user. In this study, as the mobile robot follows the movement of the
laser spot projected from atop the user’s head onto the floor, the user can determine the robot motion sequentially as the user’s own. In addition, this research takes a different approach from Takahashi’s report in that neck movement is used to move the laser spot.

In generating motion for a mobile robot, a characteristic function, which changes the instruction movement into a smooth one, is introduced. This characteristic function is called a “Kansei” transfer function in this paper [7]. Using this Kansei transfer function, the motion of the robot following the human instructional movement of a laser spot projected onto the floor is expected to be smooth and acceptable to human psychology.

2. METHOD FOR INSTRUCTION WITH NECK MOVEMENT

In this research, we propose a human-robot interface in which the user operates a mobile robot using neck movement. An operating system for a mobile robot using neck movement has not yet been reported. Such an operating system is expected to be useful even for users who have speech impairment or trouble moving their upper limbs.

As the first approach to constructing a mobile robot system based on neck movement, the facing direction of the user is measured by a 3D motion sensor attached to a cap worn on his or her head, and the instruction point to be followed by the mobile robot is calculated.

Figure 1 shows the experimental setup for estimating the instruction point using the 3D motion sensor. The coordinates of the instruction point are calculated using the following equation.

\[
(x_p, y_p) = \left( \frac{H \cos \alpha}{\tan \beta}, \frac{H \sin \alpha}{\tan \beta} \right)
\]

where \(H\) is the height of the user’s head, and angles \(\alpha\) and \(\beta\) are measured by the 3D sensor.

However, users who tested and evaluated this method stated that it was difficult to recognize the instruction point on the floor, and thus they could not operate the mobile robot easily. Figure 2 shows a representative result of the instruction point path for point-to-point movement.

As shown in the figure, the path is not smooth, and corrective operation is applied around the target position. This figure shows the difficulty of the instruction using the 3D motion sensor.

To make the instruction point of a user easier to recognize, a laser pointer is used so that the mobile robot can follow a laser spot projected on the floor. Users who tested and evaluated this instruction method stated that the use of the laser spot was very user-friendly.

3. PROPOSED SYSTEM

3.1 System construction

Figure 3 shows the setup of the system proposed in this research. The user projects a laser spot onto the floor from
a laser pointer mounted on the user’s head. The laser is a red laser with an average wavelength of 650 nm and the output power is less than 1 mW, which makes it a Class 2 device. The diameter of the laser spot is less than 6 mm when the distance is equal to or less than 5 m. The laser spot projected onto the floor (that is, the instruction point) corresponds to the direction the person is facing.

For each sampling time, ceiling-mounted CCD cameras take photographs of the laser spot, and its position is calculated by a stereo-matching program on a computer for image processing. Data on the calculated position are sent to a control computer in the omni-directional mobile robot via an Ethernet connection. The mobile robot moves by following the changes in the position data. The sampling time for controlling the omni-directional robot is 10 msec.

3.2 Omni-directional mobile robot

A mobile robot with three omni-wheels is adopted to follow arbitrary movement instructions of the laser spot on the floor holonomically. The appearance of the mobile robot is shown in Fig. 4.

From the top view, an omni-directional robot with three omni-wheels looks as shown in Fig. 5. The peripheral velocity of each wheel is denoted as $t_1$, $t_2$, and $t_3$. The coordinate system of the body is defined as $x_0$ - $y_0$, the translation speeds are $\dot{x}_0$, $\dot{y}_0$, and the rotation speed is $\dot{\theta}_0$. When the desired motion speed of the robot $v_0 = (\dot{x}_0, \dot{y}_0)$ is given, the inverse kinematics is calculated as

$$
\begin{bmatrix}
\dot{x}_0 \\
\dot{y}_0 \\
\dot{\theta}_0
\end{bmatrix}
= \frac{1}{2}
\begin{bmatrix}
1 & 0 & d_0 \\
\frac{\sqrt{3}}{2} & 0 & \frac{d_0}{2} \\
-\frac{\sqrt{3}}{2} & 0 & \frac{d_0}{2}
\end{bmatrix}
\begin{bmatrix}
t_1 \\
t_2 \\
t_3
\end{bmatrix}
$$

In Equation (1), $d_0$ is the distance between center and wheel.

4. MEASUREMENT OF THE POSITION OF LASER SPOT BY STEREO CAMERA

4.1 Stereo method

The position of the laser spot on the floor is measured by the conventional stereo-matching method using two cameras. Figure 6 shows a model of 3-D measurement of a laser spot based on the stereo-matching method using two cameras. The two cameras have identical CCDs and the same binocular vision, and are positioned so that the optical axis is parallel to the horizontal direction in the image plane. By using this setup, the correspondence of the feature points in the left and right image planes can be obtained simply by a search along an epipolar line with the same Y value.

In Fig. 6, the focal points of the left and light images are $O_{CL}$ and $O_{CR}$, and the distance is $D$. The image centers, which are binocular vision $f$ away from the focal points, are $O_x$ and $O_y$, and the feature points corresponding to the laser spots in the left and light images are $P_L(x_L, y_L)$ and $P_R(x_R, y_R)$. The position of the laser spot on the floor surface is $P(x, y, z)$. When correspondence of $P_L(x_L, y_L)$ and $P_R(x_R, y_R)$ is accomplished by searching along the epipolar line, the position of the laser spot is given by the following.
In equation (5), \( \alpha \) is the coefficient for converting the pixel value into a real distance value.

4.2 Extraction of feature point by image processing

As a first step to obtaining the 3D position of a laser spot by using the stereo-matching method, a left image and a right image are acquired from two cameras, and the position of the feature point in the images is determined by using image processing. In this research, two Hitachi high-speed image processing boards (IP7000BD) are used for acquiring two images.

The left and right images are acquired as \( YUV \) color images using the IP7000BD boards. These two images are then converted into \( YRT \) images and a thresholding process is performed to extract the feature regions of the laser spot. Note that an adequate lighting intensity from the laser spot is obtained when the distance from the laser pointer is equal to or less than 5 m, which enables extraction of the laser spot by image processing. The values of the threshold are as follows. The values for \( Y \) are 180 for the lower limit and 255 for the upper limit in a 256 gradation. The values for \( R \) are 1 for the lower limit and 150 for the upper limit in a 256 gradation. The values for \( T \) are 1 for the lower limit and 359 for the upper limit in a 360 gradation. It was confirmed that the feature point of a laser spot could be extracted without any error by using this thresholding process under indoor conditions with brightness of 500 lx. Next, the labeling process is conducted on the extracted feature region and the center of gravity is calculated. The center of gravity is the feature position in the image plane. By this procedure, feature point \( P_L(x_L, y_L) \) in the left image is obtained. \( P_R(x_R, y_R) \) is detected by searching along the epipolar line in the right image.

5. INTRODUCTION OF THE KANSEI TRANSFER FUNCTION

When intelligent machines such as robots follow movement instructions given by humans, gentleness and smoothness need to be added to the following motion of an intelligent machine (rather than simply following the movement instructions accurately without any delay) so that the motion becomes acceptable to human psychology. The authors proposed a human-robot system in which an arm robot hands a cylindrical object over to a human, and introduced an adjustment function between the movement of the human hand and the cooperative movement of the end-effector [7]. By selecting the adjustment function as a second-order lag element and by giving appropriate values to associated parameters, the following motion becomes acceptable to people. By introducing such an adjustment function into the relation between the movement instructions of the laser spot produced by the user rotating her or his neck and the following movement of the mobile robot, a gentle and smooth motion of the mobile robot (which is acceptable to a human being) is expected to be realized.

In this research, we refer to this adjustment function as a broad Kansei transfer function, which is introduced between the instruction point of the laser spot \( \vec{u}(t) \) and the position of the mobile robot \( \vec{y}(t) \) to follow the laser spot. Figure 7 shows a system including broad Kansei transfer function.

Kansei controller \( G_k(s) \), which is introduced between the output signal of sensor \( \vec{u}(t) \) and desired position of the mobile robot \( \vec{w}(t) \), is determined so that the broad transfer function \( G_k(s) \) have desirable characteristics.

A second-order lag element with a dead time element is adopted as the broad Kansei transfer function \( G_k(s) \).

\[
G_k(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} e^{-\zeta\zeta t} \]  

(6)

In Equation (6), \( \zeta \) is the damping factor, and \( \omega_n \) is the natural frequency.

The broad Kansei transfer function \( G_k(s) \) is the product of \( G_{\text{sensor}}(s) \), \( G_k(s) \) and \( G_k(s) \).

\[
G_k(s) = G_{\text{sensor}}(s) \cdot G_k(s) \cdot G_k(s) \]  

(7)

The transfer function of sensor including image processing is expressed as

\[
G_{\text{sensor}}(s) = K_{\text{sensor}} e^{-\zeta\zeta t} \]  

(8)

The transfer function of the mobile robot can be approximated by

\[
G_k(s) = \frac{K_k}{1 + T_k s} \]  

(9)

Therefore, Kansei controller is calculated as the following.

Figure 7: System including Kansei controller
\[ G_{k}(s) = \frac{G_{x}(s)}{G(s)} \cdot G_{m}(s) \cdot G_{s}(s) \]
\[ = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \frac{1 + T_s\frac{\omega_n}{\zeta}}{s + \omega_n} \cdot e^{-L_1 t} \]
\[ = \frac{\omega_n^2}{K_wK_m} \left( \frac{1 - \frac{T_s\omega_n}{\zeta}}{s + \omega_n} \right) e^{-\frac{L_1}{T_s}} \]  

(10)

The discrete time difference equation of \( w(k) \) which results from discretization of this equation preceded by a zero-order hold and followed by a sampler with the conditions that the sampling time \( T \) and the time delay \( L_1 \) becomes

\[ w(k) = \frac{1}{K_wK_m} \left[ \left( 1 - e^{-\alpha T} \right) + \left( T_s - \frac{1}{\omega_n} \right) e^{-\alpha T} \right] u(k-1) \]
\[ - \frac{1}{K_wK_m} \left[ \left( 1 - e^{-\alpha T} \right) + \frac{T_s - \frac{1}{\omega_n}}{T_s} e^{-\alpha T} \right] u(k-2) \]
\[ + 2e^{-T_s}y(k-1) - e^{-2T_s}y(k-2) \]  

(11)

6. SWITCHING MODES

When a user wants to stop the mobile robot at certain position instead of letting it continue to follow the movement of the laser spot, it would be ideal if the user could switch to “stopping mode” at that position. Conversely, when the user wants the mobile robot to follow the movement of laser spot, the mode ought to be switched from “stopping mode” to “following mode”. Therefore, a method through which the user can switch mode by controlling the position of laser spot is proposed.

6.1 Switch to stopping mode

When the mobile robot moves following the direction in which the user is facing, the robot follows the movement of the laser spot projected onto the floor as shown in Fig. 8 (a). When a user wants the mobile robot to stop, the user projects the laser spot above an LED-line on the front panel of the robot as shown in Fig. 8 (b). By positioning the laser spot above the LED line, the mode switches from “following mode” to “stopping mode”, and the robot stops at that position instead of continuing to follow the movement of the laser spot.

6.2 Switch to following mode

When a user wants to terminate the stopping mode and cause the mobile robot to resume movement, the user moves the laser spot within a rectangle on the front of the mobile robot by rotating her or his neck as shown in Fig. 9. After the system recognizes that the laser spot is within the rectangular area, the mode is switched from stopping mode to following mode. In following mode, the mobile robot follows the movement of the laser spot on the floor.

6.3 Switch to autonomous motion mode to the target

We introduce an autonomous motion mode in which the mobile robot moves to the target position for the user autonomously. The user can switch to this mode by locating laser spot within the rectangle area at the front panel of the robot as shown in Fig. 10 for more than 3 sec.

In this mode, when the user keeps locating the laser spot at a desired position on the floor for a moment, the system recognizes the user’s intention to move the mobile robot to the located position and moves the robot from the current position to the desired position automatically with a smooth trajectory.
7. EXPERIMENTAL EVALUATION OF THE SYSTEM

The effectiveness of the proposed system was evaluated through experiments.

7.1 Evaluation of the motion characteristics of the mobile robot

We conducted an experiment in which human subjects operated a mobile robot to examine the motion characteristics of the mobile robot generated through the Kansei controller. The path of the motion was analyzed. In the experiment, the subject moved the mobile robot from the initial position (circle I) to the target position (circle I’) as shown in Fig. 11. The line from the center of circle I to the center of circle I’ was parallel to the line connecting the two shoulders of the subject. The subjects were free to determine path, speed, and movement time of the mobile robot arbitrarily. The value of the damping factor $\zeta$ in the broad Kansei transfer function was fixed at 1.0 to prevent vibration, and $\omega_n$ was set at 1.0 rad/s, which was evaluated as the most acceptable movement in a preliminary experiment. In the experiment, the parameters $K_R$ and $K_{se}$ could be regarded as 1.0. The time constant of the transfer function of the robot $\tau_R$ was approximated as 10 msec. The lag element of transfer function including image processing $L_I$ was approximated as 50 msec. The sampling time $T$ is 50 msec. Fifteen healthy subjects aged from 22 to 25 participated in the experiment.

Figure 12 shows the photograph of experimental circumstance. A user operates a mobile robot on the white floor in a room. Since this research represents a fundamental approach, the surroundings of the mobile robot were simple.

As an example of the experimental results, the path of the laser spot on the floor and the path of the mobile robot are shown in Fig. 13. In Fig. 13, a circle shows the corresponding position of the laser spot and the mobile robot every 0.75 sec.

As shown in Fig.13, the path of the laser spot is not smooth because of quantization and other factors. In contrast, the path of the mobile robot exhibited a smooth profile and a moderate delay to the laser spot was observed. The generated path of the mobile robot was not a straight line between the initial point and target point, but rather described a gradual arc that represents the characteristic of the instruction given using neck movement.

We conducted an additional experiment in which the user moved the mobile robot from an initial position to the target position while avoiding a collision with an obstacle. The obstacle was a cube, 270 mm on each side, which was placed at the center between the initial position and target position. The representative result of the generated path in this experiment is shown in Fig. 14.

As shown in the figure, the generated path of the mobile robot is a smooth curve and the mobile robot successfully avoided a collision with the obstacle.
7.2 Psychological evaluation of the proposed system

Psychological evaluations were conducted to examine the effectiveness of the proposed system from the viewpoint of human psychology. A rating scale method, a questionnaire-type subjective psychological evaluation, was conducted to examine human impression of the following motion of the mobile robot based on the broad Kansei transfer function. The rating scale method is a stepwise method with seven steps between opposite adjective pairs that human subjects choose according to the degree of stimulation.

The selection of the adjective pairs used in the evaluation was conducted as follows. It was reported that the motion of a machine or robot will be interpreted by human subjects from the viewpoint of three factors: agreeableness, speed, and interest [8, 9].

- “awkward – smooth”
- “uncomfortable – comfortable”
- “slow – fast”
- “dislike – like”

These were extracted from the factor of agreeableness.

- “scary – reassuring”

This was extracted from the factor of speed.

- “difficult to operate – easy to operate”

This was extracted from the factor of interest.

The following motion of the mobile robot should not be scary but reassuring to human. From this point of view, the following adjective pair was selected.

- “scary – reassuring”

The following adjective pair was selected to evaluate human operability of the robot.

- “difficult to operate – easy to operate”

In the experiments, a subject conducted arbitrary operation of the mobile robot under three values of \( \omega_s \): 0.5 rad/s, 1.0 rad/s, and 2.0 rad/s in the broad Kansei transfer function. The value of the damping factor \( \zeta \) was fixed at 1.0. After the operation, the subject evaluated the motion trajectories of the mobile robot and the operability of the system.

Figure 15 shows the average and standard deviation of the evaluations when giving one to seven points to each step. With regard to the results of “awkward – smooth”, the averages located at the center or the right position. These show a beneficial effect of the broad Kansei transfer function to make the following trajectory smooth. When we focus on the value of \( \omega_s \), the average of the evaluations when \( \omega_s = 1.0 \) rad/s located at the light position from the center (p<0.1 adequate in t-test) except for the evaluation of “slow – fast”. The evaluations when \( \omega_s = 2.0 \) rad/s located at the left position for the evaluation of “scary and reassuring” and the evaluation of “difficult to operate – easy to operate”, which was due to quick response of the mobile robot to the instruction movement of the laser spot.

On the contrary, the evaluation when \( \omega_s = 0.5 \) rad/s located at the left position for the evaluation of “dislike – like” because the response of the mobile robot to the instructive movement of the laser spot was slightly slow.

Robot motion parameters change with the parameter value of Kansei transfer function. When \( \omega_s = 0.5 \) rad/sec, the average maximum speed of the mobile robot was 153 mm/sec, and the average movement time was 14.5 sec. When \( \omega_s = 1.0 \) rad/s, the average maximum speed of the mobile robot was 251 mm/sec, and average movement time became 10.6 sec. When \( \omega_s = 2.0 \) rad/sec, the average maximum speed of the mobile robot was 282 mm/sec, and average movement time was 9.0 sec.

It was clarified from these results that the following motion of the mobile robot to the instructive movement of the laser spot will be acceptable to human psychology by adopting the second order lag element with suitable parameter values as the broad Kansei transfer function.

8. CONCLUSIONS

In this research, we proposed a human-robot system in which a human moves a mobile robot by moving her or his neck. In order for a user to be able to control a robot easily and intuitively, a laser pointer is used to inform the desired motion trajectory to the mobile robot. In concrete terms, a laser pointer is mounted on the user’s head to project a laser spot onto the floor, and the mobile robot follows the movement of the laser spot generated by the user changing the direction in which she or he is facing. By projecting an instructive point to be followed by the mobile robot, the user can clearly recognize the relation between the direction being faced and the desired position of the mobile robot. In addition, the user can convey a motion trajectory to the mobile robot continuously, which is relative to a human.

A broad Kansei transfer function is introduced into the input-output relation between the movement of the laser spot and the following movement of the mobile robot to make the movement of the mobile robot smooth and acceptable to human psychology.

In addition, three modes are provided in the system, which can be switched by controlling the location of the laser spot. The first mode is the stopping mode, the second
mode is the following mode, and the third mode is an autonomous motion mode to the target.

The effectiveness of the proposed system was confirmed through experiments in which human subjects used an existing mobile robot from the viewpoint of the generated motion trajectory of the robot and human psychology.

To use the proposed system, the user was required to move or rotate his or her neck arbitrarily and without disability. In other words, anyone who is able to position the laser spot at the desired position using his or her neck movement can use the proposed system. However, it is important to construct a system that accommodates users who have difficulty in positioning the laser spot at the desired position using only neck movement. The desirable parameters of the Kansei transfer function differ according to the user and change with factors such as age, sex, personality, and physical condition. From this viewpoint, it is important to incorporate a mode in which the user can adjust the parameters of the Kansei transfer function into the system. These will be future focuses of our research.

When considering a mobile robot supporting a user in the same work space, the surroundings of the mobile robot become complicated. In this case, it is important for the robot to have the autonomous ability to judge the situation and to conduct an appropriate action that will help the user. This is a future task of our research.

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