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Method of position command generation by index finger motion to mitigate influence of unintentional finger movements during operation

Masaharu Komori*, Koji Kobayashi, Tatsuki Tashiro

Department of Mechanical Engineering and Science, Kyoto University, Kyotodaigakukatsura, Nishikyo-ku, Kyoto-shi, Kyoto, Japan

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ABSTRACT

Recently it has been proposed to use robots for human welfare, but current robot operation methods are not easy for novice users. Therefore, an intuitive operation method is required. Given the dexterity of the index finger, one potentially easy operating method is for an operator to use their index finger to control robotic motion, in which the robot makes the same motion as the finger. However, when the operator moves their index finger with an intended motion, it is not confirmed whether the actual finger motion is the same as the intended motion, and a difference between them possibly exists. When this happens, the robot makes a motion different from the motion intended by the operator. In this research, we studied the difference between the intended and actual index finger motion using an experiment in which it was supposed that participants manipulated a virtual object using their finger motion. The results clarified that a difference exists, and when the participant intended to move the tip of their right index finger linearly in the forward and backward directions, the actual motion was along a curve convex to the left direction. An operating method using a conversion equation to calculate the intended index finger motion of the operator from the actual motion was constructed considering the difference between the intended and actual motion. Another experiment of operating a virtual object was conducted using the proposed curvature-adjusted operating method and the conventional method, and the operation methods were compared in terms of required time, tracing accuracy, and user feedback. The results confirmed that the proposed curvature-adjusted operating method is effective overall.

1. Introduction

Robots were first adopted for manufacturing, but recently it has also been proposed to use robots in the field of welfare, that is, for care-giving and living assistance [1,2]. A robotic hand can make it possible for a supported person to do things that they cannot do alone, and it can also reduce the burden of human care-givers. However, the robot must be easy to operate. Generally, operating a robotic arm requires manipulating its position in terms of X, Y, and Z coordinates by using an operating device with buttons [1,3]. However, since this operation method is not intuitive, practice is necessary to use it and it is a heavy burden for new users [4]. Therefore, an operation method that can be used intuitively is required.

The index finger is a very dexterous body part, so people already frequently use it to conduct various activities in daily life and work. In other words, we are already accustomed to using the index finger to manipulate objects and operate machines. Therefore, if the operator can move their index finger and have that movement translated into the same motion in a robot, operation of the robot is considered to be intuitive [5–8]. In other words, if the robot moves forward when the operator moves their index finger forward and if the robot moves to the right when the operator moves their index finger to the right, then it is easy for new users to operate. For this reason, research on manipulating a robot by finger motion has been conducted. In these studies, the researchers have attached measuring devices to the finger and measured its motion while a robot is operated. Recently, non-contact sensors have been developed to easily measure the movement of a human finger. For this reason, some papers have reported on studies that measured the movement of the operator's finger with a non-contact sensor and made devices such as robots perform the same movement as the operator's [9–23].

In the finger-based control method, since the robot performs the same movement as the movement of the finger of the operator, the operator needs to move their finger accurately. However, when the operator operates the robot by the motion of their finger, it is not clear whether or not the intended finger movement of the operator accurately matches the actual finger movement. If the operator carefully moves their finger while watching it, then the finger motion might be

* Corresponding author.
E-mail address: komorim@me.kyoto-u.ac.jp (M. Komori).

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accurate, but if the operator does not pay enough attention, then the motion accuracy might decrease. If the actual movement of the finger is different from the intended motion, the motion of the robot is also different from the motion intended by the operator.

In this research, we studied index finger motion as it pertains to operating a device such as a robot. First, we experimentally investigated the difference between the finger movement intended by the operator and the actual motion, and clarified the characteristics of the difference. Next, in consideration of the difference between the intended and actual finger movement, we developed an operation method that mitigates influence of unintentional motion and makes the robot move as intended by the operator. Finally, experiments were carried out where an object was moved in virtual space using the developed operation method, and we demonstrated its effectiveness.

2. Definition of terms

Terms and concepts used in this paper to describe and utilize coordinate systems, axes, points, and related areas are defined below. The index finger of the right hand was used in this study.

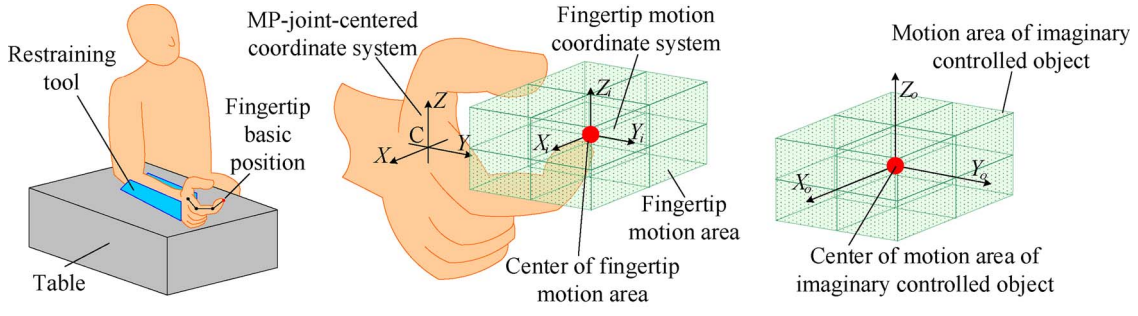
- *Basic posture*: As shown in Fig. 1(a), a participant sits on a chair and places their right forearm on a table and positions it horizontally and forward. The hand is placed so their little finger rests on the table and their index finger is on the upper side. As shown in Fig. 1(b), the hand is lightly clenched and the plane including all joints of the index finger is parallel to the horizontal plane. The tip of the index finger points to the left. A restraining tool is used to prevent changes in the position of the wrist and orientation of the palm.
- *Fingertip basic position*: As shown in Fig. 1(a), this is the position of the tip of the index finger in the basic posture, and it corresponds to the center of the fingertip motion area described later.
- *MP-joint-centered coordinate system*: As shown in Fig. 1(b), this is a right-handed rectangular coordinate system fixed at the metacarpophalangeal (MP) joint of the index finger of the operator. Its origin is the MP joint center C, and the three orthogonal axes are X, Y, and Z. When the operator faces forward, the right direction is the positive direction of the X-axis, forward is the positive direction of the Y-axis, and upward is the positive direction of the Z-axis.
- *Fingertip motion coordinate system*: As shown in Fig. 1(b), this is a right-handed rectangular coordinate system fixed in space. The origin is set to the fingertip basic position, and the three orthogonal axes are X_i, Y_i, and Z_i. These axes are parallel to the X-, Y-, and Z-axes, respectively, of the MP-joint-centered coordinate system.
- *Fingertip motion area*: As shown in Fig. 1(b), this represents the area within which the tip of the index finger moves. This area is expressed by a rectangular prism with side lengths of 30 mm in the left-right direction, 30 mm in the forward-backward direction, and 20 mm in the upward-downward direction. The center of gravity coincides with the fingertip basic position. The finger motion range is $|X_i| \leq 15$ mm, $|Y_i| \leq 15$ mm, and $|Z_i| \leq 10$ mm in the fingertip motion coordinate system. The fingertip motion area is smaller than the actual motion range of an adult index finger, so that the operator can easily move their index finger within this area. In order to make it easy to recognize the space, finger motion area is defined as rectangular prism.
- *Imaginary controlled object*: This is the virtual object that the operator moves with their finger motions. The object is displayed in virtual space on a computer screen.
- *Center of motion area of imaginary controlled object*: As shown in Fig. 1(c), this is the center of the motion area of the imaginary controlled object described later.
- *Coordinate system for motion of imaginary controlled object*: As shown in Fig. 1(c), this is a right-handed rectangular coordinate system fixed in virtual space on a display screen. Its origin is set on the center of motion area of the imaginary controlled object, and its three orthogonal axes are X_o, Y_o, and Z_o. These axes are parallel to the X-, Y-, and Z-axes, respectively, of the MP-joint-centered coordinate system. The position of the imaginary controlled object is expressed by this coordinate system.
- *Motion area of imaginary controlled object*: As shown in Fig. 1(c), this is the area within which the imaginary controlled object moves. The lengths in the left-right, forward-backward, and upward-downward directions in the motion area are in the proportions 3:3:2.

3. Investigation of intended versus actual index finger motion during operation

We carried out an experiment to clarify the difference between the intended index finger motion of the operator and the actual motion. In the experiment, an operator (participant) mimicked the motion of a virtual object by moving their right index finger to follow it. The participant watched the motion of the object first and then intentionally moved their index finger to follow the observed motion. The actual motion of the index finger was measured, and its relation to the motion of the object was analyzed.

3.1. Experimental method

As shown in Fig. 2, a participant sat in the basic posture and watched the display screen. The participant assumed that he or she was operating the imaginary controlled object displayed on the screen by moving their tip of index finger so that the motion was appropriate for the observed motion of the imaginary controlled object. Namely, the participant intentionally moved their index finger so that the motion of



(a) Basic posture, fingertip basic position

(b) MP-joint-centered coordinate system, fingertip motion coordinate system, and fingertip motion area

(c) Motion area of imaginary controlled object (virtual space on a screen)

Fig. 1. Definitions of basic posture, coordinate systems, and areas.