# Finger Motion Measurement System for Telexistence Hand Manipulation

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***Abstract*—This research focuses on finger motion measurement system of telexistence robot to realize precise hand manipulation. Wearable sensor glove which measures operator's finger joint angles is used in most cases for reproducing his/her finger motion to robot hand. However, angle-based finger motion measurement is difficult to estimate correct position of fingertip because of hand shape difference between individuals. On the other hands, optical position measurement such as motion capture can obtain exact position, but has problem of measuring stability because of occlusion. To overcome this issue, we propose a finger motion measurement system which consists of sensor glove with motion capture. To calibrate individual differences, the kinematic parameters of operator's hand such as bone length are estimated at first, and then the hand model predicts fingertip position from sensor glove data. Once the parameters are obtained, both motion capture and hand model provide position of fingertip in parallel, and the measurement becomes more stably against occlusion. The performances of the proposed system regarding parameter estimation and precision accuracy were evaluated during finger movement in 3D space.**

***Keywords—telexistence, robot hand, sensor glove, motion capture***

## I. Introduction

Telexistence is a concept that refers to the technology, which enables a human to have a real-time sensation of being at a place other than where he/she actually exist, and to interact with the remote environment [1]. Telexistence is realized by using human-like robot operated with master-slave system such as TELESAR series [2,3,4,5,6]. Many of them are equipped with anthropomorphic robot arm and hand for manual teleoperation, which are controlled by the operator's body movement in master-slave manner. That is, operator's hand gesture is measured in real-time and the action is reproduced on the robot hand at the same time. To realize precise duplication of manual operation, it is important to measure operator's motion data as precisely and stably as possible because the accuracy of reproduced robot's finger motion depends on accuracy of finger motion measurement system. In most cases, operator's hand motion is recorded by using wearable sensor gloves and joint angle data of fingers are used for controlling the joints of the robot hand. However, it is difficult to estimate correct hand postures from joint angles obtained from sensor glove unless the kinematic parameters such as bone length are exactly known, though these parameters varies from person to person. Therefore, individual difference between hands causes difficulty in precise hand manipulation of telexistence robot.

For decades many kinds of anthropomorphic robot hands have been developed [7,8,9,10] to replicate human equivalent hand manipulation, and finger motion measurement system is also used to obtain control signal and/or teaching data for the robot hand. These systems also suffer same problem of measurement accuracy of finger motion caused by individual differences, and various calibration methods to improve the accuracy are proposed. Fernando et al. [11] proposed a finger calibration method for telexistence robot which is based on predefined hand posture matching. The adjustment coefficient of joint angle was determined by the correspondence between actual input angle of operator's hand and desired output angle of robot hand. The method worked decently and realized replication of many hand shapes. However, the accuracy was limited for calibrated hand shape and not ensured for general postures.

In this study, we propose an novel five-finger motion measurement system for the operator of telexistence robot, which achieves accurate and stable position tracking of finger motion. This system consists of two components; (1) wearable sensor glove measuring joint angles, and (2) optical motion capture tracking positions finger position. The key concept of the measurement system is that these two sensing systems are used complementarily, that is, joint angle data measured by sensor glove are insufficient to obtain correct finger position but has advantage of stable measurement in comparison to the optical measurement, whereas optical motion tracking has disadvantage of measurement stability due to occlusion but can obtain accurate finger position. To combine these sensor data, this system allows to measure operator's finger motion more accurately and stably so that the robot hand can always duplicate the operator's hand manipulation as precise as possible.

## II. Finger Motion Mesurement System

### *A. System Overview*

Fig. 1 shows the finger motion measurement system which is equipped with two types of motion sensing system. The inertial measurement unit (IMU) which senses 3D rotation angle is attached to finger segment. The optical marker which emits infrared light is attached to fingertip. The emission light of optical maker is received to the motion capture camera to obtain 3D position of the fingertip.

### *B. Sensor Glove for Attitude Measurement*

An existing sensor glove system (Cobra Glove, Synertial UK Ltd.) is employed for the measurement system to obtain operator's finger joint angles at the sample rate of 30 Hz through fifteen 9-axis IMU sensors attached on the hand and finger segments. Fig. 2 shows the layout of IMU sensors on the hand. Obtained data are used for two ways. One is direct output data of finger orientation, and another is input data of

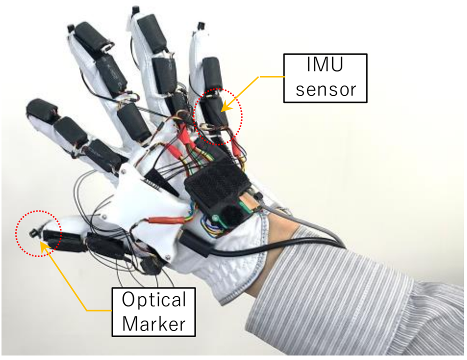


Fig. 1. Proposed finger motion measurement system. The sensing devices (IMU sensors and optical motion capture makers) are attached on a wearable glove. IMU sensors are placed on finger segments to measure the orientation, whereas optical markers are placed on fingertips to measure the position.

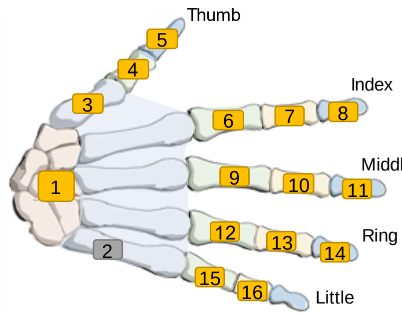


Fig. 2. Layout of fifteen IMU sensors. Each sensor fixed in finger segment obtains local rotation angle of CM (#3), MP (#4), IP (#5), MP (#6,9,12,15), PIP (#7,10,13,16) and DIP (#8,11,14) joint relative to the previous segment, whereas the root sensor (#1) measures global rotation angle of hand. Note that one sensor (#2) is not used and there is no sensor for DIP joint of little finger due to the limitation of the system.

hand kinematic model to generate predicted finger position. The prediction of finger position needs additional information regarding kinematic parameters of operator's hand, and they are separately estimated.

### *C. Motion Capture for Position Tracking*

An existing optical motion capturing system (OptiTrack, NaturalPoint, Inc.) is used to measure operator's finger motion at the sample rate of 240 Hz. The active markers are attached on five fingertips to obtain their position with high accuracy (error < 0.1 mm, in nominal terms of the tracking system). The captured data are used for two ways; One is direct output of finger position, and another is learning data of the kinematic hand model to estimate operator's parameters. The estimation procedure is described in next section.

## III. Kinematic Hand Model

A simple kinematic hand model which represents skeletal structure of human hand is introduced to estimate operator's finger position in order to complement the finger motion trajectory. For simplicity, thumb and fingers are all modeled as same kinematic chains consisting of three spherical (3DOF) joints because the IMU sensor used in the system can obtain 3D rotation angle of each joint around arbitrary axis. Although each joint of each finger actually has different DOF and rotation axis, this model can represent the rotation in the same way. Hence, the endpoint of the kinematic chain relative to the origin of the hand is formulated as below;

$$ {}^{0}\boldsymbol{P}_{endpoint} = {}^{0}_{1}\boldsymbol{T} \cdot {}^{1}_{2}\boldsymbol{T} \cdot {}^{2}_{3}\boldsymbol{T} \cdot {}^{3}\boldsymbol{P}_{endpoint} \tag{1} $$

where, ${}^{i-1}_{i}\boldsymbol{T}$ is 4x4 homogeneous transform matrix which describes position and orientation of frame of $i$-th joint ($i = 1,2,3$) relative to the previous joint. Assuming that rotation components of them (attitude of finger segment) is given, Eq. (1) derives three linear equations in terms of translation components (length of finger segment) as shown below;

$$ \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} = \begin{bmatrix} f_1(lx_0, ly_0, lz_0 \cdots lx_3, ly_3, lz_3) \\ f_2(lx_0, ly_0, lz_0 \cdots lx_3, ly_3, lz_3) \\ f_3(lx_0, ly_0, lz_0 \cdots lx_3, ly_3, lz_3) \end{bmatrix} \tag{2} $$

where, $lx_j, ly_j, lz_j$ are link length parameters of each segment ($j = 0,1,2,3$). These parameters ought to be known prior to the kinematics calculation of Eq. (1). However, these parameters are all different between individuals. If the general finger lengths are used for the parameter, it leads position errors of fingertip due to individual difference. In the proposed method, the numerical estimation is performed to know the parameters. This parameter estimation deals with individual body size difference among operators. This should be done at least once for an operator before starting hand manipulation. That is, it is performed as initial calibration of the kinematics model. Detailed calibration procedure is as below;

1. To record series of fingertip position data and finger segment attitude data while performing finger movement.
2. To substitute the pairs of position/attitude data to Eq. (2) and derive simultaneous equations in terms of link length parameters.
3. To solve the simultaneous equations via least squares and obtain the estimates of the parameters.
4. To repeat same procedure for all fingers.

Note that at least four measurement data (i.e. different finger shapes and fingertip positions) are necessary to solve the equations because of twelve unknown parameters. As long as the obtained parameters are valid, the kinematic model calculates predicted positions of operator's fingertips.

## IV. Integration of Sensor Data

Fig. 3 shows the process flow of sensor data. As mentioned above, motion capture is mainly used for position measurement of fingers whereas sensor glove is in charge of orientation measurement of fingers. Also, two sensor data are applied for estimating kinematic parameters of hand and generating predicted positions of fingers. When initial calibration (or re-calibration) is performed, the parameter estimator updates the length parameters of each joint by using latest sensor data and send them to the hand model. The predicted position data are adopted in the case motion capture system fails to track the optical marker. Furthermore, under the condition of even worse tracking, the prediction data is mainly used for keeping stable position measurement.

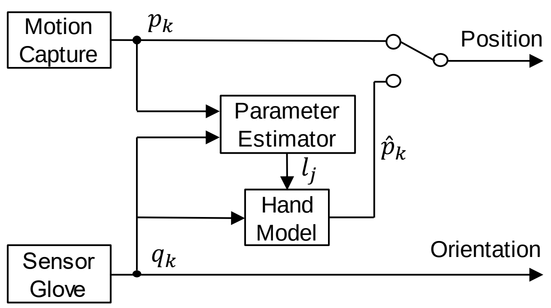


Fig. 3. Block diagram of the measurement system. The output position source is switched according to measurement quality of motion capture.

## V. Experimental Verification

### A. Parameter Estimation

An experimental measurement was conducted to verify whether the estimated parameters were valid. An adult who wore the measurement system performed some voluntary finger movement and the link length parameters were estimated by using the measurement data. Specifically, the man moved his thumb freely for approximately 20 seconds while recording the finger movement. Then, recorded data were employed for estimating the link length parameters. Table.1 shows estimated length parameters of the thumb. As shown in Table. 1, estimated finger length is different from the measured length which was visually measured by using a ruler. The error of each segment length is distributed up to approximately ± 10mm. However, the total length of each finger is similar. Please note that the ruler measurement might be also different from the true bone length of the phalanges.

### B. Evaluation of Predicted Position Data

The experimental measurement described above was also conducted to evaluate the prediction accuracy of the hand model with valid parameters. After parameter estimation, subsequent measurement was performed for the prediction. Specifically, the man moved his thumb freely same as the previous measurement, and recorded IMU sensor data were inputted to the hand model and the predicted finger position was obtained. Besides, the motion tracking data were used as the reference of the prediction. Fig. 4 shows predicted finger position calculated from the hand model, and true positions of them recorded from the motion capture are also shown. As shown in Fig. 4, the predicted position is quite accurate, and the root mean square error (RMSE) of the finger position is on average 5.22mm.

TABLE I. Estimated Parameters of Finger Segments

| Thumb length (mm) | Estimated | Measured |
|---|---|---|
| metacarpus | 32.2 | 43 |
| proximal phalanges | 36.2 | 35 |
| distal phalanges | 41.1 | 30 |
| total | 109.5 | 108 |

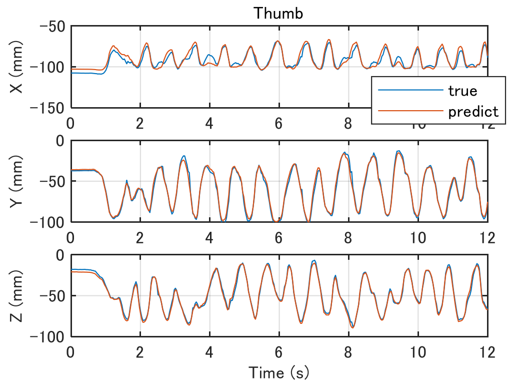


Fig. 4. Predicted position of the person's thumb with the true value. These graphs represent time series of position data for each axis, which was recorded while the person performed voluntary finger movement.

## VI. Conclusion

In this study, a five-finger motion measurement system was developed for the precise hand manipulation of robotic finger. This measurement system consists of two different types of motion sensors to compensate disadvantages of them in order to keep accurate and stable measurement of finger motion. In the system, there is a kinematic hand model to predict the fingertip positions. An experimental measurement was conducted to evaluate validity of the prediction method, and high prediction accuracy was confirmed. However, the prediction accuracy seems to depend on the position tracking quality of motion capture during the parameter estimation because the outlier affects the solution. Therefore, outlier elimination based on the measurement reliability is necessary.

## Acknowledgment

This research is supported by ACCEL Program from Japan Science and Technology Agency, JST.

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