A Data Adjustment Method of Low-priced Data-glove

based on Hand Motion Pattern

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Abstract—A data glove is one of the major interfaces used in the field of virtual reality. In order to get detailed data about the finger joint angles, we must use a data glove with many sensors. However, a data glove with many sensors is expensive and a low-priced data glove does not have enough sensors to capture all the hand data correctly. In our previous work, we propose a method to obtain all finger joint angles by estimating the pattern of hand motion from the low-priced data glove sensor values. In our experiment system, we assumed some representative hand motion patterns as grasping behavior. We also assumed that other hand motions can be represented by synthetic motion of the representative patterns. In our previous work, we used the data glove with sensors covering two joints of each finger. In this paper, we estimate the finger joint angles when using the data glove whose sensors cover only the middle angle of each finger.

Keywords–Data-glove; Hand motion estimation; Finger joint angles estimation.

Figure 1. 5DT Data Glove 5 Ultra

Figure 2. DG5 VHand

I. INTRODUCTION

Virtual Reality (VR) is a rapidly growing research field in recent years. VR technologies give us various advantages. There are simulators to practice an operation and to fly a plane as examples of VR technologies. These simulators enable us to avoid the risk and to save on cost. VR researches that targets to households also have been attracted. A data glove is one of the major interfaces which are used in the field of VR. It measures curvatures of fingers using bend sensors. In order to obtain accurate hand motions, it is necessary to use a data glove which has many sensors, but it is expensive. It is preferable that an interface is small scale and low cost. Various types of researches about data glove have been conducted [1][2][3]. On the other hand, there is a low cost data glove which measures an angle for each finger through one sensor. But it cannot get detailed data directly. For example, the 5DT Data Glove 5 Ultra and DG5 VHand have a single sensor on each finger, so they have five sensors in the whole hand (see Figures 1 and 2). However, there are three finger joints for each finger, a single sensor can not measure all of these three angles directly. In our laboratory, we have proposed a method to get plausible user hand motion pattern from the low-cost glove. This method estimates the kind of hand motion patterns using each relation among angles of fingers during operation. Then, it estimates all finger joint angles by estimating the types of hand motion patterns from the correlation between each finger angle in the
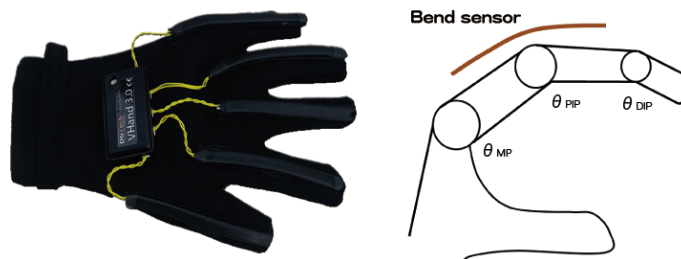
hand motion pattern [4]. We assume some representative hand motion patterns, and consider that other hand motions can be represented as a synthetic motion of the representative hand motion patterns. In addition, we calculate the ratio of each representative motion pattern. Moreover, estimating each finger angle using the result, we express any hand motion patterns other than the representative hand motions. In our previous work, we have used 5DT Data Glove (see Figure 1) whose sensors cover two joints of each finger. Here, we estimate finger joint angles when using the data glove DG5 VHand (see Figure 2) whose sensors cover only the middle angle of each finger.

The rest of the paper is structured as follows. In Section II, we describe how to estimate finger joint angels. In Section III, we apply this method to the data-glove that sensor positons are limited. In Section IV, the experimental results are shown. Finally, we conclude in Section V.
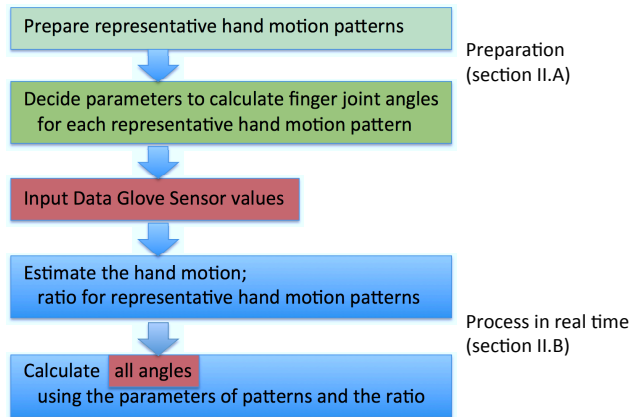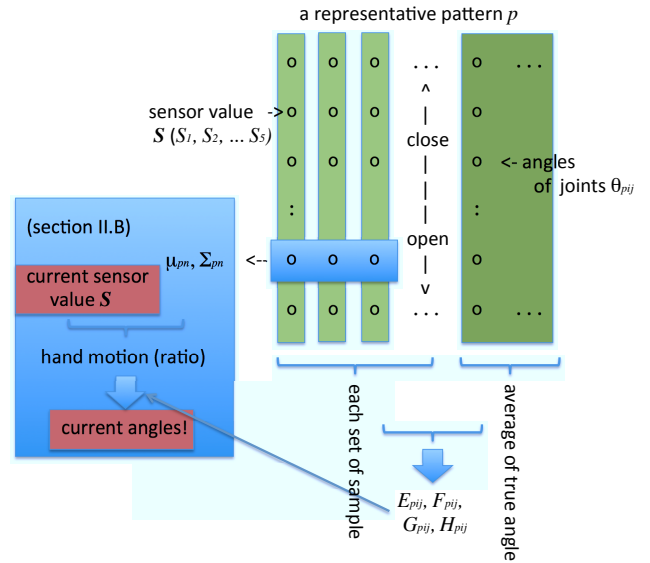
Figure 3. Overview of method

Figure 4. Detail of method

II. ESTIMATION OF FINGER JOINT ANGLES

In section II, we describe an estimation method of finger joint angles using 5DT data glove which has been developed in our laboratory (see Figure 3).

A. Representative Hand Motion Patterns

To estimate finger joint angles, this method limits user's hand motion to grasping motion. First of all, we chose four representative hand motion patterns (see Figure 5)[4] from human's grasping motion (Figure 6)[5].

Furthermore, we assume that a human's grasping motion can be represented as a synthetic motion of representative hand motion patterns. To derive three finger joint angles from a single sensor value, we use the following method (see Figure 4). We sample many sets of the sensor values with the low-priced data glove when some subjects open their hand first and then close it to each representative hand motion patterns. Also, we sample the sets of the true angles of finger joints for the same representative patterns, provided that we use true angles obtained from a data glove which has a lot of sensors. We use Immersion CyberGlove as data glove with a lot of sensors. Then, the sensor values and the true angles of finger joints at the same time are associated. We show an example of correspondence in Figure 7.

We derive the following numerical formulas using this correspondence.

$$\theta_{pi1} = \frac{2}{3}\theta_{pi2} \quad (1)$$
$$\theta_{pi2} = E_{pi2}S_i^3 + F_{pi2}S_i^2 + G_{pi2}S_i + H_{pi2} \quad (2)$$
$$\theta_{pi3} = E_{pi3}S_i^3 + F_{pi3}S_i^2 + G_{pi3}S_i + H_{pi3} \quad (3)$$

where pattern p is one of representative hand motion patterns. Angles θ_{pi1}, θ_{pi2} and θ_{pi3} express the DIP, PIP, and MP joint angle of the finger i for the pattern p. The DIP, PIP, and MP joint mean the first, second and third joint of a finger respectively. The S_i is sensor value of finger i. And E_{pij}, F_{pij},

G_{pij} and H_{pij} are constant parameters for the pattern p, finger i and joint j. These parameters, E_{pij} to H_{pij}, are calculated by pre-experiment. Besides, DIP joint angle is obtained by proportional connection with PIP joint angle (eq. 1)[6]. Joint angles of finger i of pattern p are obtained by these numerical formulas.

B. Hand Motion Estimation and Angles Estimation

To represent user's hand motion as synthetic motion of representative hand motion patterns, we need to know how similar the user's hand motion is and to which representative hand motion patterns. Then, we set the following formula based on the probability density function of the multivariate normal distribution for n points in the five dimensional feature amount space.

$$L_{pn} = exp\{-\frac{1}{2}(\boldsymbol{S} - \boldsymbol{\mu}_{pn})^T \boldsymbol{\Sigma}_{pn}^{-1}(\boldsymbol{S} - \boldsymbol{\mu}_{pn})\} \quad (4)$$

where $\boldsymbol{S}$ is the sensor value vector. And $\boldsymbol{\mu}_{pn}$ and $\boldsymbol{\Sigma}_{pn}$ represent mean vector of sensor sample values, and variance-covariance matrix of sample point n (an integer satisfying $1 \leq n \leq$ a number of samples) in representative hand motion pattern p. Besides, $\boldsymbol{\mu}_{pn}$ and $\boldsymbol{\Sigma}_{pn}$ are obtained by pre-experiment for an average user. If the sensor values are obtained actually from the glove, we select the maximum value according to the following formula.

$$L_p = \max_n\{L_{pn}(\boldsymbol{S} : \boldsymbol{\mu}_{pn}, \boldsymbol{\Sigma}_{pn})\} \quad (5)$$

Thus, we get the likelihood on representative hand motion pattern p in current sensor values. After that, we decide the ratio r_p of hand motion pattern p according to the following formula.

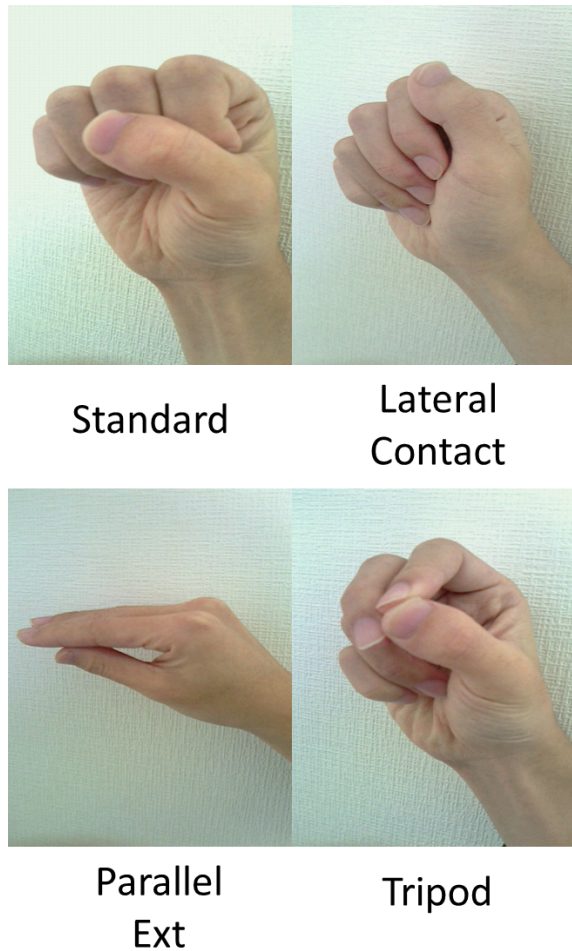$$r_p = \frac{L_p}{\Sigma_{p=1}^P L_p} \quad (6)$$

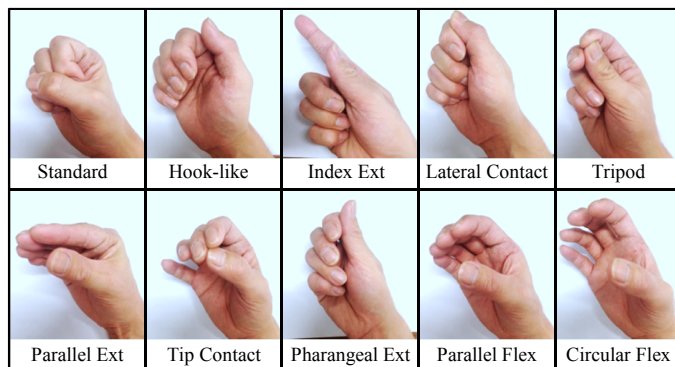Figure 5. Representative hand motion patterns

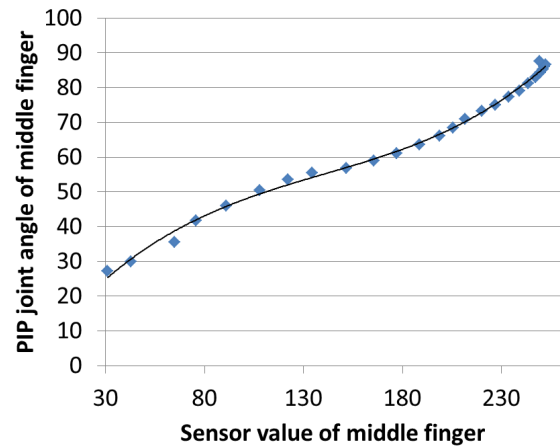Figure 6. Candidates of representative motions

Figure 7. Example of correspondence

where P is the total number of representative hand motions, which takes the value of four. As stated above, we can obtain θ_{pij} and r_p. At last, each angle θ_{ij} of current hand posture is derived by the following formula.

$$\theta_{ij} = \sum_{p=1}^{P} r_p \cdot \theta_{pij} \qquad (7)$$

III.   DATA-GLOVE THAT SENSOR POSITIONS ARE LIMITED

In section III, we describe an estimation method of finger joint angles using DG5 data glove whose sensor positions are limited only to PIP joints.

A. MP Angle for Representative Hand Motion Pattern

Although we mentioned above representative hand motion patterns are selected, the pattern Parallel Ext. is almost the motion related only to MP joints. When doing the Parallel Ext. pattern, the sensor values hardly change. We tentatively use three other patterns as representative hand motion patterns for now.

For the 5DT data glove whose sensors cover PIP and MP joints, the DIP angle is related to PIP directly, as mentioned in the previous section. It means the sensor values contain all of their information. However, using DG5 whose sensors are only on PIP, the motion of MP does not change the sensor value. Of course, we assume that the hand motion is a grasping one, so the MP angle of a finger is related to the PIP angle of the same finger. Then we can assume that the MP of a finger is related to the PIPs of all fingers.

We consider a new estimation model to obtain angles for representative hand motion patterns using multiple regression analysis. First, we make a estimation equation with explanatory variable is a set of sensor values, and response variable is each MP joint angle, as follows.

$$\theta_{pi3} = \sum_{f=1}^{5} C_{pif3} S_f + I_{pi3} \qquad (8)$$

where θ_{pi3} is MP joint angle of finger i of representative pattern p, S_f is sensor value of finger f, and C_{pif3} and I_{pi3} are constant.

Now, a subject opens his hand first and then closes it to each representative pattern with DG5 data glove, the set of sensor value $S_f(time)$ of finger f at $time$ is sampled. Then, the subject moves his hand as each same pattern with CyberGlove which has many sensors, the set of angle value $\theta_{pi3}(time)$ is sampled as true one.

Here, we should get the constant C_{pif3} and I_{pi3}. The residual sum of squares Q is represented as in (9).

$$Q = \sum_{time} \left\{ \theta_{pi3}(time) - \left(\sum_{f=1}^{5} C_{pif3} S_f(time) + I_{pi3} \right) \right\}^2 \quad (9)$$

Focusing on coefficient C_{pi13} where $f = 1$;

$$
\begin{aligned}
Q = \sum_{time} \Bigg\{ & \left(S_1(time) C_{pi13} \right)^2 \\
& + 2 S_1(time) C_{pi13} \left(\sum_{f=2}^{5} C_{pif3} S_f(time) + I_{pi3} \right) \\
& - 2 \theta_{pi3}(time) S_1(time) C_{pi13} \\
& + \left(\sum_{f=2}^{5} C_{pif3} S_f(time) + I_{pi3} \right)^2 \\
& - 2 \theta_{pi3}(time) \left(\sum_{f=2}^{5} C_{pif3} S_f(time) + I_{pi3} \right) \\
& + \left(\theta_{pi3}(time) \right)^2 \Bigg\}
\end{aligned}
\quad (10)
$$

Using the partial differentiations with C_{pi13};

$$
\frac{\partial Q}{\partial C_{pi13}} = 2 \sum_{time} S_1(time) \left\{ \sum_{f=1}^{5} C_{pif3} S_f(time) + I_{pi3} - \theta_{pi3}(time) \right\}
\quad (11)
$$

Using the partial differentiations also with C_{pif3} and I_{pi3};

$$
\frac{\partial Q}{\partial C_{pif3}} = 2 \sum_{time} S_f(time) \left\{ \sum_{f'=1}^{5} C_{pif'3} S_{f'}(time) + I_{pi3} - \theta_{pi3}(time) \right\}
\quad (12)
$$

$$
\frac{\partial Q}{\partial I_{pi3}} = 2 \sum_{time} \left\{ I_{pi3} + \sum_{f=1}^{5} C_{pif3} S_f(time) - \theta_{pi3}(time) \right\}
\quad (13)
$$

The constant C_{pif3} and I_{pi3} to be obtained make Q represented as the minimum of the equation from (9). And the C_{pif3} and I_{pi3} that make Q minimum satisfy following equation.

$$\frac{\partial Q}{\partial C_{pif3}} = \frac{\partial Q}{\partial I_{pi3}} = 0 \quad (14)$$

Solving this, coefficient C_{pif3} and constant I_{pi3} are obtained to estimate MP joint angle for representative pattern with (8). The angles of PIP are obtained directly from the sensor value with (2), and the angles of DIP are also obtained only from PIP with (1).

B. Hand Motion Estimation with Pseudo-Inverse Matrix

When the variance of sensor values is zero at the sample point n of representative hand motion pattern, the variance-covariance matrix will be abnormal at the sample point n. It means the inverse matrix of variance-covariance matrix of sensor values Σ_{pn}^{-1} can not be obtained, and the likelihood for the sample data of representative pattern p can not be obtained with (4).

So we use Moore-Penrose pseudo-inverse matrix to solve it. The variance-covariance 5×5 matrix of sensor values Σ_{pn}^{-1} which is abnormal at the sample point n is represented as next equation with $5 \times r$ matrix A_{pn} and $r \times 5$ matrix B_{pn} where $\text{rank}(\Sigma_{pn}) = r$;

$$\Sigma_{pn} = A_{pn} B_{pn} \quad (15)$$

Here the Moore-Penrose pseudo-inverse matrix Σ_{pn}^{+} for Σ_{pn} is described as:

$$
\begin{aligned}
\Sigma_{pn}^{+} &= B_{pn}^T \left(A_{pn}^T \Sigma_{pn} B_{pn}^T \right)^{-1} A_{pn}^T \\
&= B_{pn}^T \left(B_{pn} B_{pn}^T \right)^{-1} \left(A_{pn}^T A_{pn} \right)^{-1} A_{pn}^T
\end{aligned}
\quad (16)
$$

Using this Moore-Penrose pseudo-inverse matrix Σ_{pn}^{+} for (4) instead of the inverse matrix of variance-covariance matrix of sensor values Σ_{pn}^{-1} at the sample point n where inverse matrix can not be defined, the likelihood is obtained and the ratio of each hand motion pattern is determined with (5) and (6), respectively. Now, we can use a low-priced data glove whose sensors cover only the middle angle of each finger to estimate all finger joint angles of current hand posture with (7).

IV. EXPERIMENT AND RESULT

We performed an experiment to confirm the effectiveness of the method described above. The experiment system was constructed using the DG5 Data Glove whose sensor positions are limited only on middle joints. Other hand motions that were different from representative patterns were tested. The minimum of Activities of Daily Living (ADL) needs the following hand motions (see Figure 8) [7].

1) Power grasps (used in 35% ADLs)
2) Precision grasps (30% ADLs)
3) Lateral grasps (20% ADLs)
4) Extension grasps (10% ADLs),
5) Tripod grasps,
6) Index pointing, and
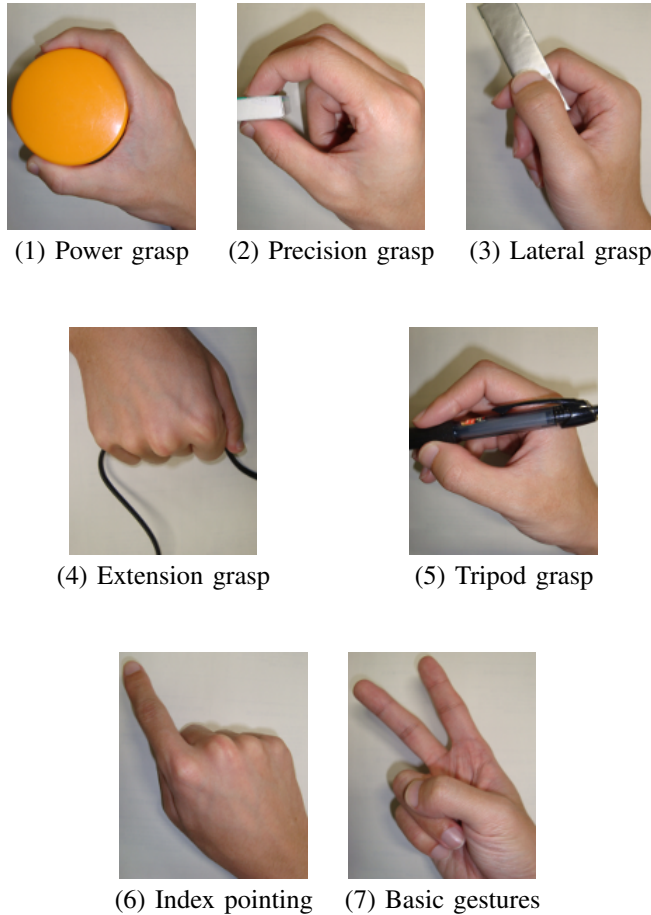7) Basic gestures.

We tested five motions; 1)–5).

(1) Power grasp   (2) Precision grasp   (3) Lateral grasp

(4) Extension grasp   (5) Tripod grasp

(6) Index pointing   (7) Basic gestures

Figure 8. Hand motions needed for ADL

TABLE I. ERROR OF FINGER JOINT ANGLES [DEGREE]

	thumb	index	middle	ring	little	average
Power G.	7.3	12.0	10.5	12.5	10.0	10.5
Precision G.	8.1	9.2	7.2	7.0	6.8	7.7
Lateral G.	9.4	6.0	8.8	7.5	10.5	8.4
Extension G.	9.8	8.1	11.0	11.3	9.0	9.9
Tripod G.	8.5	8.5	7.2	11.6	10.9	9.3
average	8.6	8.7	8.9	10.0	9.4	9.2

Figure 9. Result CG for Power grasp

Figure 10. Result CG for Precision grasp

The subjects opened their hands and then closed them to each test pattern 1)–5) with DG5 data glove. The average of estimated joint angles were compared with the true angles obtained from CyberGlove which had many bend sensors.

Table I shows the average error of finger joint angles. Each error is around 10 degrees. The result using the 5DT data glove whose sensors cover two joints of each finger also had about 10 degrees error [4]. This means that the lower-priced data glove can obtain joint angles accurately enough.

Actual hand posture images and the CG images generated from estimated joint angles are shown in Figures 9 and 10. The MP joints that were not covered with bend sensors are estimated from the sensors on PIP joints.

V. Conclusion

In this paper, we described a useful method using a low-priced data-glove based on hand motion patterns. It estimates all finger joint angles using the data glove whose sensors cover only the middle angle of each finger. The method has been expanded from our previous method using a data-glove whose sensors cover two joints of each finger. A data glove is one of the major interfaces which are used in the field of VR. It measures curvatures of fingers using bend sensor. However, in order to obtain accurate hand motions, it is necessary to use an expensive data glove which has many sensors. On the other hand, there is a low cost data glove which measures an angle for each finger through one sensor.

It cannot get detailed data directly. Our method estimates plausible user hand motion patterns using each relation among angles of fingers during the operation of the low-cost glove first. Then, it estimates all finger joint angles by estimating the types of hand motion patterns from the correlation between each finger angle in the hand motion pattern. We assumed some representative hand motion patterns, and considered that other hand motions could be represented as synthetic motion of these. The ratio of each representative motion pattern is calculated using Moore-Penrose pseudo-inverse matrix, and all finger angles are estimated using multiple regression analysis. With the low priced data-glove being useful, it is expected that VR systems that target households will become more popular. In the future, we should reconsider the representative hand motion patterns because we removed Parallel Ext. from our previous research based on medical knowledge. We should also expand the target hand motion patterns to various ones that are not only grasping patterns.

ACKNOWLEDGMENT

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