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Measurement and Description of Human Hand Movement

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Abstract. The actual movement and the coupled relationship of human fingers are very important for the analysis of human hand grasp, but there are very few effective ways to detect it. The paper introduces a method with wearable measuring sensors to realize the real time measurement and description of human fingers' movement during hand grasping. A data glove for real-time measuring the movement of each joint of all the fingers was designed. The finger movements of three typical human hand grasps were measured, and the coupled relationship and the complete motion trajectory of all five fingers were got and described.

1 Introduction

When grasping, human hand usually has two restriction modes: inter-finger-restriction and intra-finger-restriction, due to the complex distribution of biomechanical drive mode and structural constraints between bones and joints inside the hand. The inter-finger-restriction refers to the constraint among finger joints, which makes human hand have a specific range of motion, and the intra-finger-restriction refers to the combined constraint co-produced by tendons and muscles, which reflects the coupled motion produced by the ligaments and tendons' drive among middle finger, ring finger and little finger [1-2]. It's very difficult to accurately observe and describe the true motion of human hand during grasping. Therefore, to accurately measure and describe the movement of each finger and the coupled relationship among fingers during grasping is of great significance for the study of human hand grasp.

Human hand has a very complex structure which is composed of 27 bones, 17 joints and more than 20 DOFs (degree of freedom), and it can complete a variety of complex and sophisticated grasps. Human hand model has great significance for the research of human hand grasp. The complete motion description of human hand needs real-time processing of various data and results in a very large amount of calculation, so it is usual to simplify the human hand model in order to improve the processing speed. To simplify the human hand model, the elements that have little impact on the hand motion are usually ignored. Currently, there are a number of different ways to model the human hand. Bray [3] and Du, Yuan et al. [4] established a hand model with 30 DOFs. Kuch, J. [5] established a human hand model with 23 DOFs. DLR laboratory [6] established a human hand model having 24 DOFs. Van der Smagt P. [7] established a human hand model of 23 DOFs. Chalfon J. [8] established a human hand model with 22 DOFs.

For any human hand model, if the joint movements of the human hand could be obtained, then the motion of the whole hand can be described. There are some researches on the description and

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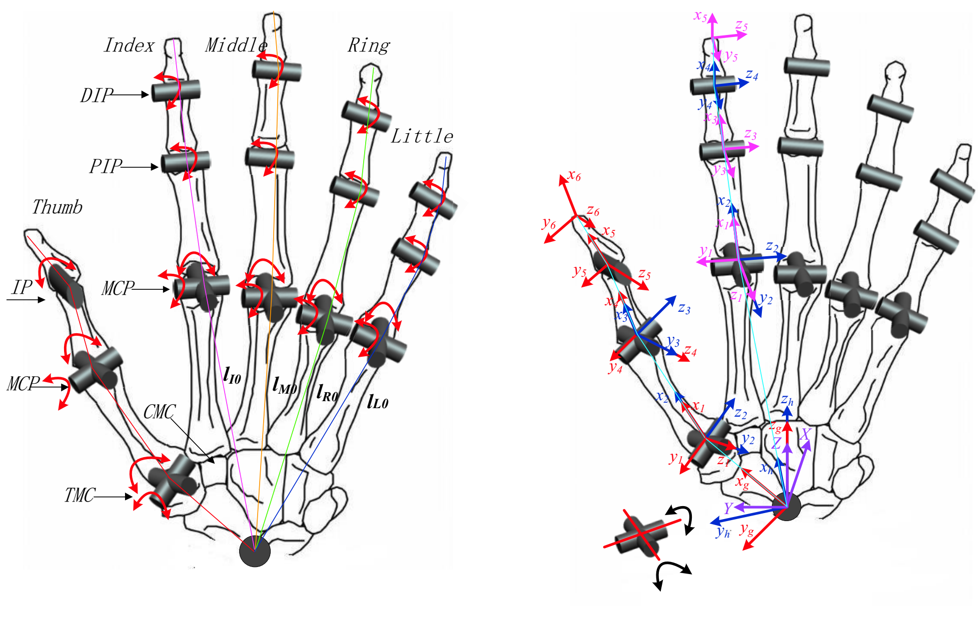
measurement of human hand. Nishikawa et al [9] proposed a method based on curvature transition to solver the posture of human hand. Kasprzak et al. [10] developed a computer vision system to detect the static posture change order of human hand by identifying the sequence of color images. N. Miyata et al.[11] used magnetic resonance (MR) instrument to track the hand joint posture. In the previous research of human hand movement, it’s very difficult to accurately detect and describe the real joint angles change and the relationship of human hand joints during different hand graspings.

In order to analyze human hand grasp, we developed a hand movement measuring system, proposed a matrix to describe hand posture, and did experiments on three typical human hand grasps with the measuring system and description method. This paper is organized as follows. Section 2 established a simplified model of the human hand and presented a kinematic description method of hand movement. Section 3 introduced the joint angel measuring system. Section 4 introduced the experiments on three typical human hand grasps and presented the real motion trajectories and coupled relationships of five fingers. Section 5 gives the conclusion.

2 Human hand modelling

2.1 Structure model of human hand



a) Structure model of human hand **b)** Kinematic model of human hand

Figure 1 Model of human hand

By analyzing the anatomical structure of human hand and referring to the medical experience, a simplified structure model ofhuman hand with 21 DOFs was established by following these rules: 1) The thumb is independent of other fingers, 2) The adduction and abduction of each finger are independent, 3) Motion frequency does not affect the relationship of joints, 4) The hand is independent to the wrist and the arm. As shown in Figure 1-a, the thumb has 5 DOFs, of which each of the carpometacarpal joint (TMC) and the metacarpophalangeal joint (MCP) has 2 DOFs (flexion/extension, adduction/abduction), and the interphalangeal joint (IP) has 1 DOF (flexion/extension); each of the other four fingers has 4 DOFs, of which each of the interphalangeal joint (PIP) and the distal interphalangeal joint(DIP) has 1 DOF (flexion/extension), and the metacarpophalangeal joint (MCP) has 2 DOFs (flexion / extension and adduction / abduction).

2.2 Kinematic model of human hand

Referring to the simplified structure model of human hand (Figure 1-a), the kinematic model of human hand was established and shown in Figure 1-b. Suppose the reference frame origin is at the wrist position, and l_{T0}, l_{T1}, l_{T2} and l_{T3} sequentially represent the distance between the carpometacarpal joint and wrist, the metacarpal length, the proximal phalanx length, the distal phalanx length. The other four fingers use the similar description method, l_{F0}, l_{F1}, l_{F2}, l_{F3} ($F=l$, M, R, L) sequentially represent the distance between the wrist joint and MCP, the proximal phalanx length, the middle phalanx length, the distal phalanx length. Referring to the hand measuring method of [12-14] and GB-T16252-1996, we measured the dimension variables of 3 people's hands (right) 10 times, and after the statistical treatment of the measurement data the values of those variables are shown in Table 1.

Table 1 The measured values of the subject hand(mm)

Name	Hand length	l_{T0}	l_{T1}	l_{T2}	l_{T3}	L_{I0}	L_{I1}	L_{I2}	L_{I3}	L_{M0}	L_{M1}
Size	200.5	18.2	57.1	32.1	35.1	11.0	31.3	23.2	23.3	110.	35.0
Name		L_{M2}	L_{M3}	L_{R0}	L_{R1}	L_{R2}	L_{R3}	L_{L0}	L_{L1}	L_{L2}	L_{L3}
Size		25.0	29.1	108	29.2	26.1	27.8	10.8	26.8	18.1	20.1

Referring to Figure 1-b, the Denavit-Hartenberg (D-H) method was used to establish the kinematic models of the thumb and other four fingers respectively. The D-H transformation matrix is:

$$T_{i-1}^{i}=\begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{(i-1)} \\ \sin\theta_i\cos\alpha_{(i-1)} & \cos\theta_i\cos\alpha_{(i-1)} & -\sin\alpha_{(i-1)} & -\sin\alpha_{(i-1)}d_i \\ \sin\theta_i\sin\alpha_{(i-1)} & \cos\theta_i\sin\alpha_{(i-1)} & \cos\alpha_{(i-1)} & \cos\alpha_{(i-1)}d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Substitute the corresponding D-H parameters of each finger into the transformation matrix and multiplyeach joint's transformation matrix in turn as shown in Equation (2), then the motion of the finger can be described.

$$T_0^N = T_0^1 T_1^2 T_2^3 \cdots T_{N-1}^N \quad (2)$$

Transformation matrix T_0^N which represents the position and posture of the finger tip is a function of N variables of the finger joints, where N is the number of finger joints. If we can measure the joint angles of a hand at any moment, then we can calculate the corresponding motion of any finger according to formulas (1) and (2).

3 Human hand movement measuring system

As shown in Figure 2, a human hand movement measuring system composed of a computer and a data glove was developed. The data glove uses fifteen 9-axis magnetic sensor (MEMS) units to measure joint angles of a hand by sticking one sensor unit on the middle of each phalanx of a finger, and each sensor unit consists of an acceleration sensor, a gyro sensor and a magnetic sensor. The computer is responsible for the receiving, processing and displaying of the measured data transmitted from the data glove, and it communicates with the data glove through RS232.

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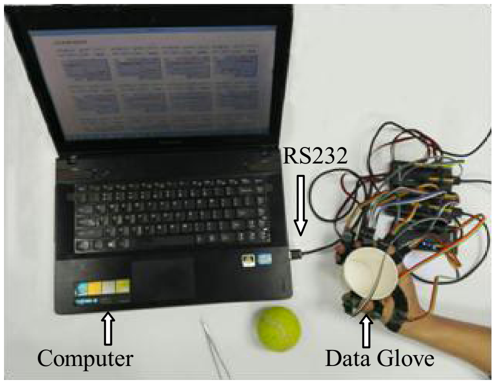
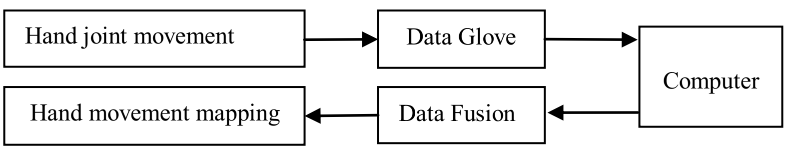


Finger 2 Human hand movement measuring system

Using this data glove, we can obtain each joint's original movement data when a hand is grasping. Then the filtered data with Dynamic Kalman filter was fused with the acceleration data, angular velocity data and geomagnetic data toreduce the constant drift error and the interference of noise. Finally, the obtained joint movement data was substituted into the finger kinematic model so as to get the motion trajectory of each finger. Figure 3 shows the data processing flow ofthe human hand movement measuring system.



Finger 3 Data processing flow of the human hand movement measuring system

4 Examples of measurement, description and coupled relationship of hand movement

Human hand can do numerous types of grasps. We select the Schlesinger taxonomy as the grasping library to do the measuring experiment which were cylindrical grasp, tip, hook and snap, palmar, spherical grasp, lateral [15].

Human fingers have coupled movements because of the presence of inter-finger-restriction and intra-finger-restriction, which have two main forms as: 1) the coupled movements of distal interphalangeal joint with interphalangeal joint caused by inter-finger-restriction, 2) Multiplefingers' coupled movements caused by intra-finger-restriction (such as the coupled movements of ring finger when the middle finger is in flexion). Such coupled movement relationships of fingers were got from the experimental data as follows.

(1) Coupled movements of inter-finger

The DIP and PIP has coupled flexion when the human hand completes the cylindrical grasp, and the relationship is shown in Figure 4-a and equation (4), where θ_{DIP} is the angle of the DIP flexion and θ_{PIP} is the angle of the PIP flexion.

$$\theta_{DIP} \approx \frac{2}{3}\theta_{PIP} \tag{4}$$

The TMC and MCP have coupled flexion when the human hand completes the spherical grasp and the relationship is shown in Figure 4-b and equation (5), where θ_{FE}^{T-TMC} is the angle of the TMC flexion of the thumb and θ_{FE}^{T-MCP} is the angle of the MCP flexion of the thumb.

$$\theta_{FE}^{T-MCP} \approx \frac{9}{10}\theta_{FE}^{T-TMC} \tag{5}$$

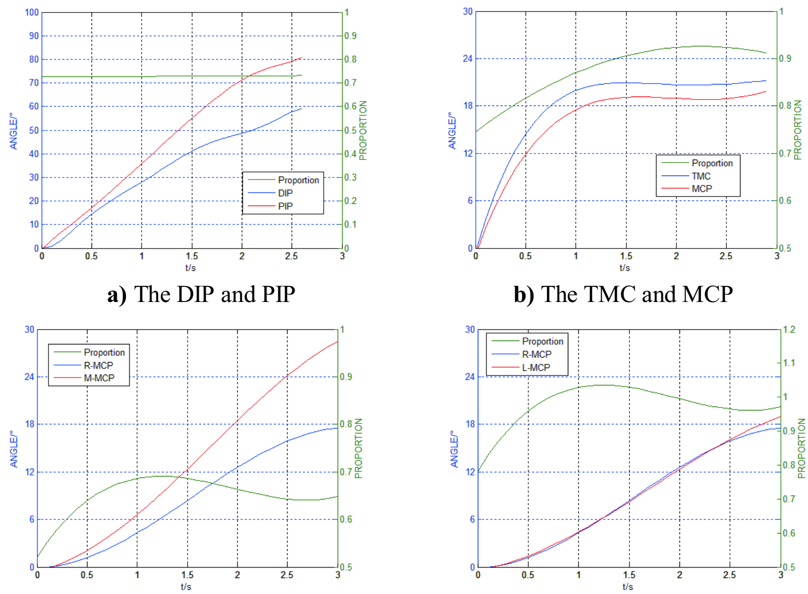
(2) Coupled movements of intra-finger

The MCPs of the middle finger and the ring finger have coupled flexion when the human hand completes the palmar grasp and the relationship is shown in Figure 4-c and equation (6), where θ_{FE}^{M-MCP} is the angle of the MCP flexion of middle finger, θ_{FE}^{R-MCP} is the angle of the MCP flexion of ring finger.

$$\theta_{FE}^{M-MCP} \approx \frac{3}{2}\theta_{FE}^{R-MCP} \tag{6}$$

The MCPs of the ring finger and the little finger has coupled adduction/abduction when the human hand completes the spherical graspand relationship is shown in Figure 4-d and equation (7), where θ_{AA}^{R-MCP} is the angle of the MCP adduction/abduction of little finger.

$$\theta_{AA}^{R-MCP} \approx \theta_{AA}^{L-MCP} \tag{7}$$



a) The DIP and PIP **b)** The TMC and MCP

c)The middle and ring finger's MCP **d)** The ring and little finger's MCP

Figure 4 The finger's Coupled flexion

Those above coupled movement relationships got from experiments will be helpful not only for analyzing the human hand grasp as well as the design of bionic hand but also for designing human hand rehabilitation devices.

5 CONCLUSION

In order to survey the actual movements of human fingers, a measuring system and motion description method were presented. Firstly, based on the anatomical structure of the human hand a structure model with 21 DOFs and the kinematic model of each finger with D-H method were established, then a human hand movement measuring system was designed, and last 6 typical human hand grasps were used as grasping library to be measured, and the motion trajectory of each finger and the coupled movement relationships of fingers in different types of grasps were got. The conclusion of coupled movement relationships of fingers has guiding significance for research work such as bionic hand design, human hand rehabilitation and so on. The hand measuring and description method presented in the paper can also be used for the measuring and analysis of other types of human hand grasps.

References

1. Cutkosky, M.R., Wright, P.K.: Modeling Manufacturing grips and correlations withdesign of robotic hands. In: Procedings of the IEEE International Conference onRobotics and Automation, pp. 1533–1539 (1986)
2. Virtual Technologies. Reference Manual. CG081998-2-1 (1998)
3. M Bray, E Koller-Meier, P Muller, NN Schraudolph, L Van Gool: Stochasticoptimization for high-dimensional tracking in dense range maps. In: Proc. IEEE.Vis. Image Signal Process, pp. 501–512 (August 2005)
4. Du, H., Charbon, E.: 3d Hand Model Fitting for Virtual Keyboard System. In:IEEE workshop on Applications of Computer Vision, pp. 31–36 (February 2007)
5. Kuch, J.J., Huang, T.S.: Human Computer Interaction via the Human Hand: A Hand Model. In: Signals, systems and Computers, Conference Record of the Twenty Eighth Asilomar Conference, pp. 1252–1256 (1994)
6. http://www.dlr.de/rm/desktopdefault.aspx/tabid-3820/6244_read-9009/
7. van der Smagt P, Stillfried G (2008) Using MRI data to compute ahand kinematic model. In: 9th conference on motion and vibrationcontrol (MOVIC), München, Germany
8. Chalfon J., Renault M., Younes R., Ouezdou F.B.. Muscle force prediction of the human hand andforearm system in highly realistic simulation [A]. IEEE/RSJ International Conference onIntelligent Robots and Systems Proceedings [C], 2004: 1293-1298
9. A. Nishikawa, A. Ohnishi, F. Miyazaki, "Description and recognition ofhuman gestures based on the transition of curvature from motion images,"Proceedings of IEEE International Conference on Automatic Face and Gesture Recognition, 552-557, 2003.
10. W. Kasprzak, A. Wilkowski, K. Czapnik, "Hand Gesture RecognitionBased on Free-Form Contours and Probabilistic Inference," InternationalJournal of Applied Mathematics and Computer Science, v. 22(2), 437-448, 2012.
11. N. Miyata, M. Louchi, M. Mochimaru, and T. Kurihara, "Finger Joint Kinematics from MR Images," in IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2005, pp. 2750 – 2755
12. J. W. Garrett, "Anthropometry of the hands of male air forceflight personnel," Tech. Rep., Aerospace Medical Research Laboratory, Air Force Systems Command, Wright-Patterson AirForce Base, Ohio, USA, 1970.
13. J. W. Garrett, "Anthropometry of the hands of female air forceflight personnel," Tech. Rep., Aerospace Medical Research Laboratory, Air Force Systems Command, Wright-Patterson AirForce Base, Ohio, USA, 1970.
14. S. R. Habib and N. N. Kamal, "Stature estimation from hand andphalanges lengths of Egyptians," Journal of Forensic and LegalMedicine, vol. 17, no. 3, pp. 156–160, 2010.
15. Taylor C. L., Schwarz R. J.. The anatomy and mechanics of the human hand[J]. Artificial limbs, 1955, 2(2): 22-35