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A FUNCTION DESCRIPTION FOR THE HUMAN UPPER LIMB POINTING MOVEMENTS PERFORMANCE

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Abstract- **The human motor system is mechanically complex and need to be described by using a large number of degrees of freedom. The controlled operation of such a system requires a reduction of mechanical redundancy. The coordination and synergies among the muscles and joints can be used for the reduction. In this paper, synergy is discussed through the analysis and comparison of human upper-limb pointing movements. All movements were recorded by a Vicon 3D motion analysis system. The synergy in the pointing movement of upper-limb was found among the different joint angles. A function method is used to describe the pointing performance. The different joint angles can be fitted by the same function curve. The pointing movement performance can be determined by the fitting parameter vector and the start and end states. Based on this result, a typical motion pattern can be described by a smaller set of variables.**

***Keywords* - Synergy, pointing movement, upper limb, motion pattern**

I. INTRODUCTION

The variability and flexibility of upper limb movements reflect the mechanical redundancy of the musculoskeletal system. Typically, the human arm involving three main joints: wrist, elbow and shoulder contains seven mechanical degrees of freedom. Most natural human activities such as reaching, walking, writing, etc., require coordination among muscles and joints.

The problem posed in motor redundancy was first recognized systematically by Bernstein [1]. Bernstein defined motor coordination as the process of mastering redundant degrees of freedom of the moving organ, in other words its conversion to a controllable system. Determining how this conversion process takes place is known as Bernstein's problem.

Bernstein proposed that the motor apparatus was functionally organized into synergies or classes of movement patterns. Synergies are classes of movement patterns involving collections of muscle or joint variables that act as basic units in the regulation and control of movement. Synergies are used by the nervous system to reduce the number of both controlled parameters and afferent signals needed to generate and guide an ongoing movement. According to Bernstein, certain synergies are often associated with a particular muscle group and can therefore be at least partially defined by morphology and anatomy. Other synergies can be more clearly related to a given task and provide a basis for "motor equivalence."

The study of synergies has led to the identification of many kinds of invariant movement features. Laquaniti et al. showed [2] that, although individual variations occurred, shoulder and elbow motions were generally tightly coupled. The hand trajectories of humans drawing geometrical figures like ellipses and circles in free space have the same overall shape independent of the starting position or orientation of the figure. Flash's studies showed [3] that, when moving the hand between the pairs of targets in the horizontal plane, subjects tended to generate roughly straight hand path with single-peaked, bell-shaped speed profiles which independent of the part of the wok-space in which the reaching movement was performed. For lower limbs studies, quantitative analysis of gait synergies was studied [4] by used principal component analysis. Relative phase was used [5][6][7] as an order parameter to describe coordination changes between segments with the change of gait pattern. The order parameter was defined as the relationships or cooperativities between limbs or body segments, and this is obvious one kind of the synergies.

In this paper, the pointing tasks were observed and analyzed, in order to find out the synergies among the different tasks and arm joint angles during the movement performances. A function was proposed to represent the synergies of the relationships among the segments of upper limbs.

II. METHODOLOGY

Fig.1 shows the parameters defined in this study for the pointing movement of upper-limb in a sagittal plane.

P_s the position of shoulder center,
P_{ini} the initial position of arm tip,
P_{ter} the terminal position of arm tip,
θ_i the initial position angle,
θ_t the terminal position angle,
l_i the horizontal distance between P_s and P_{ini},

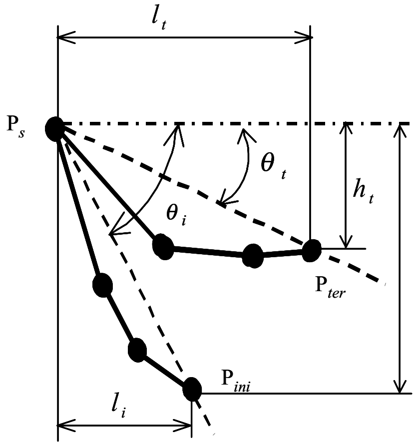

Fig. 1. The initial and terminal positions of target-reaching movement of upper limb in a sagittal plane

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Abstract

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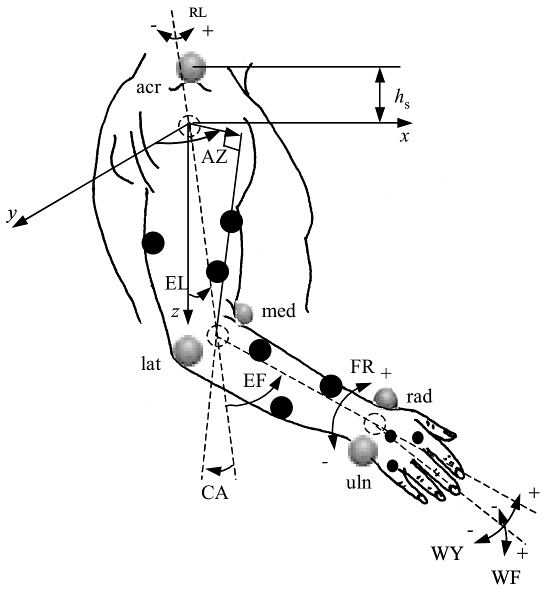

Fig. 2. Marker arrangement and joint coordinate systems. Joint markers are bright and labeled. Segment markers are dark. Joint centers are dotted.

h_i the level difference between P_s and P_{ini},
l_t the horizontal distance between the P_s and P_{ter},
h_t the level difference between P_s and P_{ter}.

Because of dimensional differences among subjects, it is necessary to normalize the pointing movement tasks. The two pointing movement tasks can be treated as identical only when meeting the following conditions,

1) two pointing tasks have the same initial angle (θ_i), terminal angle (θ_t), and $(l_t - l_i)/l_0$ or $(h_t - h_i)/l_0$, when l_0 is the length of the arm,
2) the joints of upper-limb (shoulder, elbow and wrist) are at their neutral positions as the starts and ends of the movement.

Five young and healthy male subjects voluntarily attended in this study. Their average age, height and body mass were 28±2 year, 1.74±0.04 m and 62±5 kg, respectively.

A VICON motion analysis system with four cameras was used to record the movements.

An upper-limb consists of three segments, upper-arm, forearm and hand, with seven active degrees of freedom, named azimuth, elevation, roll, elbow flexion, forearm rotation, wrist flexion and wrist yaw. As showed in Fig. 2, Azimuth (AZ) is the rotation about the vertical axis through the shoulder center. Elevation (EL) is the rotation from vertical position about horizontal axis through the shoulder joint. Elbow flexion (EF) is defined to be zero with the arm fully extended. Roll (RL) occurs about the axis of the upper arm. Forearm rotation (FR) occurs about the axis of the forearm. For wrist flexion (WF), a positive angular displacement refers to wrist flexion, a negative ones to wrist extension. Positive and negative wrist yaws (WY) refer to radial and ulnar deviation respectively.

Fourteen reflective markers were placed on the upper limb, as showed in Fig. 2. Three non-collinear markers per segment were used to monitor the movement of each segment during the pointing task p4erformance. The joint centers and joint axes are defined with five markers at the acromion, the lateral and medial epicondyle, and lateral and medial to the wrist flexion axis.

Static and calibration measurements were conducted to determine the joint centers. The centre of the wrist at the time t is at the middle point of the ulnar and radial wrist markers:

$$C_W(t)=[P_{uln}(t)+ P_{rad}(t)]/2 \,, \qquad (1)$$

The center of the elbow joint is at the middle point of the medial and lateral elbow markers:

$$C_E(t)=[P_{med}(t)+ P_{lat}(t)]/2 \,, \qquad (2)$$

The shoulder center is considered to be h_s inferior to the acromion marker.

$$C_S(t)=P_{acr}(t)-e_z\, h_s \qquad (3)$$

where e_z is the vertical unity vector of the laboratory coordinate system.

In order to minimize the influence of different movement amplitudes, the data were normalized for each trail. All joint angles were normalized using the formula

$$\theta_t=[\ \theta_t-\min(\theta_t)]\ /\ [\max(\theta_t)-\min(\theta_t)] \qquad (4)$$

III. RESULTS

Fig.3 shows the angular displacement of the motion of seven degrees of freedom in one typical pointing movement. Compared with other angular displacement during the task performance, the movement of the hand relative to the forearm (WY and WF) is small. Therefore, only the other fives will be considered.

The normalized curves of displacement have the similarities in shape, so it is possible to use a same function to fit those curves. The produce of an exponential function combining with a sinusoidal function is employed for curve fitting. The function is defined as,

$$f(t)=k_1[t^a \bullet \sin(k_2\, t+b_2)]+b_1 \qquad (5)$$

where a is the character parameter, k_1, k_2 are the scaling parameters, and b_1, b_2 are the translating parameters.

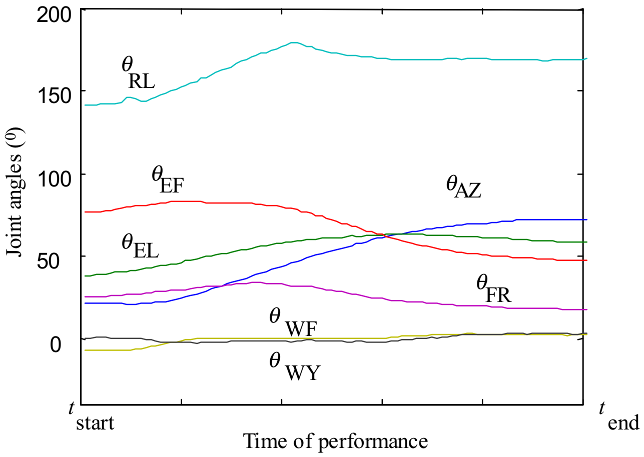

Fig. 3. Joint angles of upper-limb in one pointing movement performance

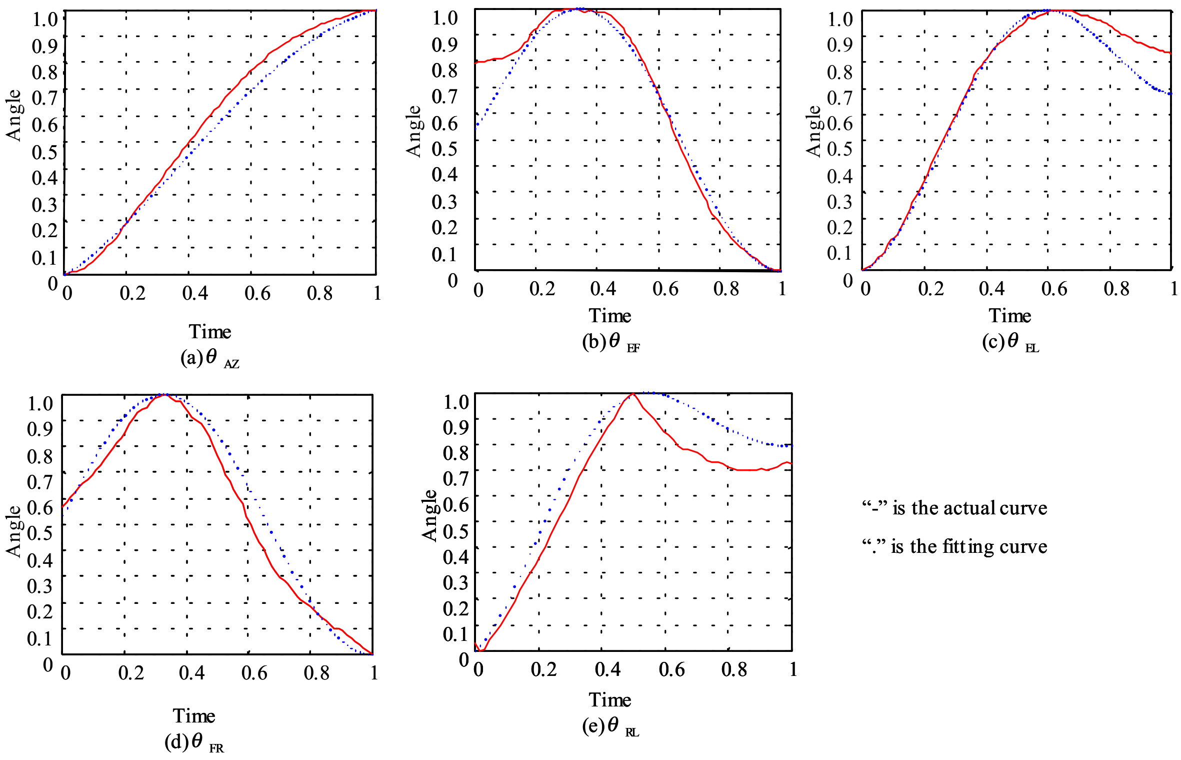

Fig. 4. Curve fitting for angles

The least mean squared method is used to fit the curves. There are many choice for the constraint conditions, and in this study, one of the prime ones is to keep the differential coefficients of $f(t)$ being zero at the start time t_{start} and the end time t_{end}. This is based on the assumption that the upper-limb is static at these two moments. Then the velocities will be zero too.

Figs. 4 shows the fitted curves and the experimental ones. The parameters used for each angle fitting are listed in Table 1, and the variances of errors are listed in Table 2. The results show that it is feasible to use the function, Equ.5, to fit the different angular displacement of upper-limb during one pointing performance in an acceptable accuracy.

The parameters for different movement are the matrix D=[a k_1 k_2 b_1 b_2]^T. The scaling and translating parameters k_1, k_2, b_1, and b_2 can be determined according to the start state and end state. A=[a_{AZ} a_{EL} a_{EF} a_{RL} a_{FR}]^T can be seen as a characteristic feature to determine the trajectory of whole upper-limb, i.e. A is a synergy matrix of human upper-limb movement.

TABlE 1

The parameters for the curves fitting

Angles	AZ	EF	EL	FR	RL
a	0.3	0.1	0.75	0.01	1.5
k1	1.0077	0.527	0.6761	0.503	0.795
k2	1.5708	4.7124	-4.7124	4.7124	-4.7124
b1	-0.0077	0.528	0.676	0.5027	0.796
b2	0	0	4.7124	0	4.7124

TABLE 2

The variances of the errors of fit the angle curves

Angles	AZ	EF	EL	FR	RL
Cov(a)	0.0010	0.0035	0.0030	0.0025	0.0026

IV. DISCUSSION

Carrying angle (CA) was defined in the experiments (see Fig. 2). It is the angle between the ulna and the extension of the humerus, when the arm is in the anatomical position. This angle occurs not only due to a tilt in the humeral axis at the humeroulnar joint, but also due to an angulation of the ulna itself, showing large variations among individuals. It must be considered if the coordinate system is to be transformed between the upper-arm and forearm. Carrying angle is normally between 5 and 15^0 for men and 10 and 25^0 for women. The carrying angles were between 9^0 and 12^0, b average of 11^0 obtained from reference measurement.

The similarities can be found among the trajectories of different pointing tasks. It shows that the pointing movements in different grades have the same movement pattern. The same trajectories similarities can also be found in the curves of the same joint angles in different task performance. It shows that there are some coordinative relationships or synergies between the joints and muscles of the upper-limb.

For the great complexity of musculoskeletal system, the coordination between the angles of the upper-limb was studied first in this paper. A functional method was used to fit and unite the different angles. In data fitting, A=[a_{AZ} a_{EL} a_{EF} a_{RL} a_{FR}]^T can be seen as a characteristic feature to determine the trajectory of whole upper-limb, i.e. A is a synergy of human upper-limb movement. Because of the variance of different human body, A

is not the same for different people. It may relate to the physiological parameter, muscle group feature and some personal habit, just like the handwriting which also relates to such features.

The scaling and translating parameters k_1, k_2, b_1, and b_2 of different angles can be determined by the start and end states. Based on the results, the whole process of movement performance will be estimated when the movement pattern (eg. pointing), the start state and the end state are defined. Thus, the number of the needed parameters to determine the upper-limb movement is reduced.

In data fitting, there are many constraints (eg. position and speed of the start and end point) may be considered, but only the prime ones will be taken as method limitation. In this study, the values of velocity at start and end point are chosen being zero, which is necessary for the development of power upper-limb prosthesis. There are errors between the fitting curves and original curves. The errors need to be considered when the fitting curves are used to design the power upper-limb prosthesis or to simulate the movement of upper-limb. Compensate metric can be used to improve the design or the simulation.

The results in this paper may be widely used in many fields. As mentioned above, the matrix $P=[D_{AZ}\ D_{EL}\ D_{EF}\ D_{RL}\ D_{FR}]$ can be used for the powered prosthesis design and control. Due to the differences existed between normal and abnormal subjects, $A=[a_{AZ}\ a_{EL}\ a_{EF}\ a_{RL}\ a_{FR}]^T$ can be used in rehabilitation evaluation.

V. CONCLUSION

The synergies have been found in a pointing movement performance of upper-limb, in this study the motion in seven DOF of upper-limb can be described in the same function way. The task performance can be estimated by the parameters in the function together with the start and end states.

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