

Synergic analysis of upper limb target-reaching movements

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Accepted 5 February 2002

Abstract

The topological invariance and synergies of human movements are discussed through the analysis and comparison of upper-limb target-reaching tasks. Five subjects were asked to perform different target-reaching tasks with different indices of difficulty, and the movements were captured using a Vicon 3D motion analysis system.

Topological invariance was observed in the trajectories of different task performances. After normalization, the trajectories of the arm tips had very close patterns for different target-reaching tasks. Synergy in the target-reaching movements of the upper limbs was also found among the different joint angles. The joint angles can be fitted using the same format of functions proposed in this study. The parameters in the function can be taken as a characteristic feature of target-reaching movement patterns. A target-reaching movement can be determined by these parameters and the start and end positions. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Synergy; Target-reaching movement; Upper limb; Motion pattern

1. Introduction

Researchers and clinicians have been interested in understanding the kinematics and kinetics of the upper-limb system for many years (Anglin and Wyss, 2000; Buckley et al., 1996). Understanding of the activities of daily living is required for the design of good orthoses or prostheses and provides input to biomechanical models. Due to the variability and complexity of the tasks, the nature of free arm movements is different from the human gait, which is restricted, repeatable or cyclic (Rau et al., 2000). There are no standard activities for the arm. If arm motion analyses become routinely used for diagnosis or rehabilitation evaluation, a set of discriminating (i.e. normal versus pathological) tasks or a set of desired functional tasks should be established.

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

By coordination among the movement motors, humans can control the great complex redundancy system perfectly. How the nervous system determines in what way to perform a given motor task in order to achieve the desired behavioral goals has long aroused the curiosity of researchers. This problem posed in motor redundancy was first recognized systematically by Bernstein (1967), who defined redundancy as being when more than one motor signal can lead to the same trajectory of a given motor system. Identical motor signals can lead to different movements under non-identical initial conditions or in the presence of variations in the external force field. Bernstein also 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 (Bernstein, 1967). 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. Certain synergies are often

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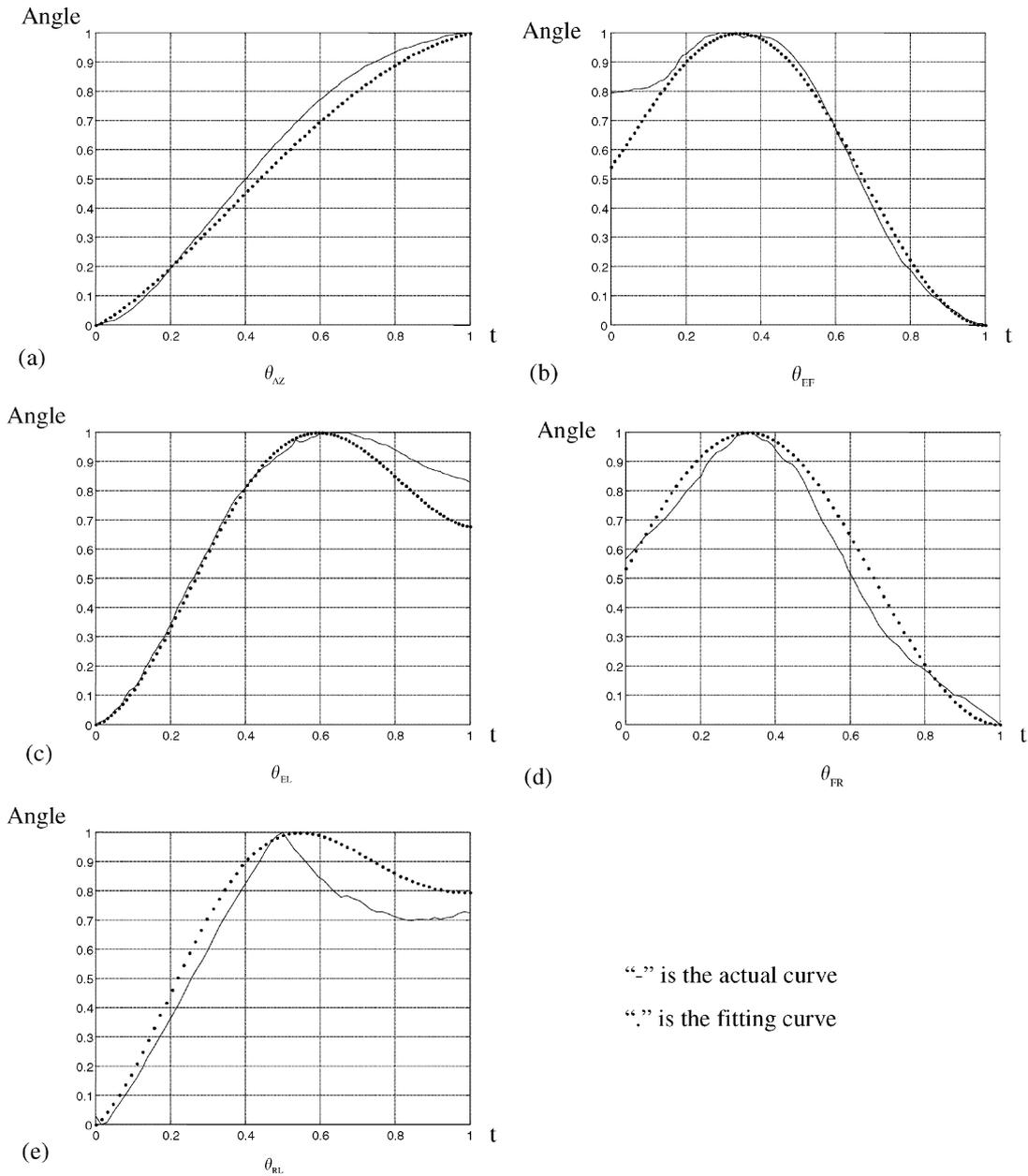


Fig. 9. Curve fitting for angles.

Table 3
The parameters for the curves fitting

Angles	AZ	EF	EL	FR	RL
A	0.3000	0.1000	0.7500	0.0100	1.5000
k_1	1.0077	0.5270	0.6761	0.5030	0.795
k_2	1.5708	4.7124	-4.7124	4.7124	-4.7124
b_1	-0.0077	0.5280	0.6760	0.5027	0.7960
b_2	0	0	4.7124	0	4.7124

Table 4
The variances of the errors of fitting the angle curves

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

study has the same or even better error level of the fifth order polynomial fitting. Higher order polynomial or other complex techniques may get the better fitting

results, but the number of the fitting parameters will increase, and the parameters in such techniques (such as high-order polynomial) do not have such regularity as parameters in Eq. (7) (scaling and translating parameters). It is difficult to use them to describe and define the synergies.

The results in this paper can be widely used in many fields. The function description of arm movements can largely reduce the parameters required to simulate arm motion, and to control a powered upper-limb orthosis or robot arm.

5. Conclusion

It can be concluded that topological invariance and synergies can be found in target-reaching movements of human upper limbs. The joint angles of the upper limb can be described in the same format of functions. The movements can be determined by the parameters, together with the start and end positions. The above results can be applied widely in biomechanical modeling, orthoses design, control theory and rehabilitation evaluation.

Acknowledgements

The study was supported by RGC Direct Allocation (Grant Number A-PC16), The Hong Kong Polytechnic University.

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