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A finger motion model for reach and grasp

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ABSTRACT

This study aimed to develop a model that describes human finger motion for simulation of reach and grasp for selected objects and tasks. Finger joint angles and timing of their changes were measured for six subjects as they reached 20–40 cm and grasped cylindrical handles (1.3–10.2 cm D) of varying orientation (vertical/axial). The empirical results from multiple regression analyses served as inputs to allow a fourth order polynomial to predict motion of each finger joint. The proposed model showed good fit with observations, with high coefficients of determination from 0.54 to 1 and reasonable errors from 0.04° to 5.44° for all conditions considered. The proposed finger motion model was implemented in an existing kinematic hand model to employ a contact algorithm for refined prediction of grip posture and to illustrate its predictive power by graphically displaying the opening and closing of the hand.

Relevance to industry: Finger joint motions during reach and grasp are needed for prediction of (1) tendon excursions for study of work-related musculoskeletal disorders, (2) required space for the hand, (3) finger locations on work objects, and (4) hand grip postures and strength.

1. Introduction

The aim of this work was to develop a model that can describe finger motion during reach and grasp. Finger motion models can be used with kinematic hand models to predict hand postures. Information of hand postures is needed for designing tools, controls, handles, and other objects that are grasped, held or used by the hand.

1.1. Importance of hand study

First, hand posture determines the space required to perform manual tasks. Baker (1960) measured the required space for using hand tools by two dimensional photographic images. These results are useful for the specific tools examined under static conditions, but cannot be easily generalized to other sizes of tools or different tools, or to dynamic tasks. Using a three dimensional motion capture system, Grieshaber et al. (2009) measured hand space envelopes of hose insertion jobs of different insertion methods. Although this method is useful for dynamic tasks, the findings are also not easily applied to other object sizes and shapes. Choi (2008) demonstrated the use of a three dimensional kinematic model to predict space required for holding cylindrical handles. The study can be applied for various object conditions, but cannot predict the required space during reach. Finger motion models are needed to describe how the fingers move during reach and grasp.

Second, final hand posture is an important factor determining hand strength (Blackwell et al., 1999; Fransson and Winkel, 1991; Shivers et al., 2002). Those studies examined the effect of grip span on grip strength by measuring subjects' maximal force with different handle separations. Since the relationship between grip posture and grip strength has been investigated, further information about grip posture will permit evaluation of grip strength. Finger motion models can contribute to predicting accurate terminal grip postures by providing a finger rotation algorithm during reach and grasp.

Last, hand posture affects tendon loads and excursions and stresses on adjacent tissues, such as synovial membranes and nerves (An et al., 1983; Armstrong et al., 1984; Armstrong and Chaffin, 1978; Landsmeer, 1961a, b). Previous studies have shown that tendon excursion is associated with repetitiveness in industrial jobs and the risk of work-related musculoskeletal disorders (WMSDs) of the upper extremities (Choi, 2008; Marklin and Monroe, 1998; Marras and Schoenmarklin, 1993; Moore et al., 1991; Schoenmarklin et al., 1994; Wells et al., 1994). However, since most studies only examined tendon excursion at the wrist, finger motion models are needed to consider tendon excursion at fingers for more detailed evaluation of jobs.

1.2. Prehension behavior and kinematic models

In developing a hand model, an empirical study of human prehension can provide data for inputs into the model. Prehension

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