VISUALIZATION OF MULTI-DIGIT MANIPULATION MECHANICS

Zong-Ming Li, Shouchen Dun
Hand Research Laboratory, Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, Pennsylvania, U.S.A.

Introduction

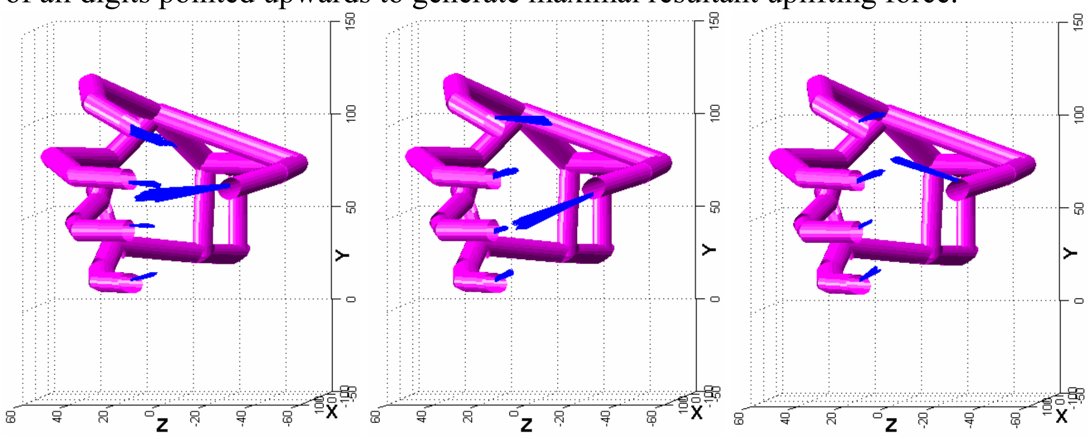
Manipulation of hand-held objects in 3D space is a complex task. Understanding how individual digits interact with a hand-held object provides helpful information for hand tool designers, researchers, clinicians, and occupational therapists. At the object-digit interface, the contact mechanics can be represented by three force and three torque components. Six-component force/torque transducers can register all the three forces and three torques at the digit-object interface, and therefore are advantageous in the study of manipulation mechanics. The large number of force and torque signals from multiple force/torque transducers are difficult to interpret and therefore making experimental research of manipulation a challenging task. The purpose of this study was to develop a 3D visualization tool for the investigation of the contact mechanics at the object-digit interfaces during manipulation tasks.

Methods

A 3D stick-figure hand model was created based on digitized 23 anatomical landmarks of the hand. Five miniature 6-component force/torque transducers (4 × Nano17 for the fingers, 1 × Mini40 for the thumb, ATI Industrial Automation, NC) were used to record force and torque data at the tips of individual digits. Thirty channels of force/torque signals from the transducers were collected by a 16-bit analogue-digital converter (PCI-6031, National Instrument, Austin, TX) installed in a computer. The transducers were mounted on a custom-made rectangular aluminum handle for object manipulation. Coordinate frames were established at each transducer, on the handle, and at the base of the MicroScribe digitizer. To visualize the force vectors at the digit-tips, the coordinates of the hand landmarks in the MicroScribe coordinate frame and the force vectors in local transducer coordinate frames were transformed to a common coordinate frame defined on the handle. One healthy right-handed, male subject participated in the experimental study. During the tests, the participant sat in a chair by a testing table. The forearm was strapped to an arm holder in neutral rotation position. The instrumented handle was fixed on the testing table by a C-clamp through an adapting plate. With the hand of the subject gripped on the instrumental handle, the landmarks of the instrumented handle and the transducers, as well as the anatomical landmarks of the hand were digitized using the MicroScribe digitizer for the purpose of coordinate frame establishment and transformation as described above. The subject performed three different maximum isometric voluntary contraction tasks: (1) grasping, (2) rotating in pronation, and (3) lifting.

Results

The 3D hand model and representative force vector clusters in a single trial of grasping, rotating, and lifting tasks are shown in Figure 1. Each cluster was formed by displaying all the 3D force vectors during the period of "stabilized" maximum effort in a trial. The magnitude and orientation of the force vectors of individual digits were strongly dependent on the task. Compared to the grasping and lifting tasks where forces were more evenly distributed among 4 fingers, forces in the rotating tasks were more concentrated on the two radial fingers, which was an advantageous strategy to produce pronation torque. In the grasping tasks, there was a trend that the force vectors of the four fingers converged. During the rotating tasks, there was a trend that the lower was the finger, the greater the projection angle, and the force vectors of the thumb pointed towards the ulnar aspect (-24.7 degrees). Therefore, the force vectors of individual digits tended to form a force couple to generate pronation torque. During the lifting tasks, the force vectors of all digits pointed upwards to generate maximal resultant uplifting force.



(a) (b) (c)

Figure 1. Three-dimensional hand model and representative force vector clusters at the digit-tips in tasks of (a) grasping, (b) rotating in pronation, and (c) lifting. Note that the magnitudes of all the force clusters within a task were equally scaled to achieve a reasonable visualization effects.

Discussion

The employment of 6-component force/torque transducers enabled us to construct 3D force vectors at the digit-object interfaces. Our preliminary results showed that during 5-digit manipulation, the human subject tended to maximize task efficiency by utilizing different force coordination strategies for different tasks. Complex force vector coordination patterns during manipulation tasks could be directly perceived through visualization. The 3D visualization tool developed in the current study could provide expedient and intuitive understanding of the mechanical interaction at the object-digit interfaces and the coordination among multiple digits. It could potentially be an effective tool for the understanding of human hand control and ergonomic designs that involve the usage of multiple digits. Further development of the current visualization tool will focus on incorporating kinematic data synchronized with force/torque measurement so that a relationship of the dynamic hand motion and manipulation mechanics could be established. The integration of force/torque data and kinematic data not only provides a dynamic visualization of grasping mechanics, but also allows for more advanced biomechanical studies such as the calculation of joint torques and muscle/tendon forces.