Modeling the Role of Passive Dynamics of Hands in Grasping and Manipulation

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The human hand movements have been studied for a long time still the role of hand biomechanics in achieving dexterity has not been fully understood. The hand biomechanics is unique due to the presence of long tendons and multi-articulate muscles. The hand biomechanics leads to passive visco-elastic properties of the hand. The exact influence of the passive visco-elastic properties on hand movement controls is not clear.

We are interested in modeling the role of passive hand dynamics during intricate object grasping and manipulation. It is clear that passive hand properties are important for error corrections to achieve desired tasks under uncertainties. We believe that, beyond error correction, the passive dynamics plays a critical role in transferring the hand muscle forces into the finger tip forces with optimal muscle coordination and control. By modeling and analyzing the exact contribution of passive dynamics we plan to advance our understanding of the human hand controls, and also design robotic hands that replicate passive hand biomechanics in order to achieve natural grasping and manipulation.

To achieve the desired grasping and manipulation the hand muscles produce moments about the wrist and finger joints. The muscle moments lead to coupling effects of multiple segments. The major factors that contribute to the coupling of multiple limb segments are: (1) passive properties due to the musculotendon structures that span multiple segments, and (2) dynamic coupling torques due to the acceleration and Coriolis components. Our focus is on deriving a model that describes the passive properties of the hand joints, specifically, the index finger metacarpophalangeal (MCP) flexion/extension. The model involves the coupling between the wrist motion and the finger motion due to the musculotendon structure of the hand. Based on this model we investigate the contribution of the passive visco-elastic component to the total torque generated at the MCP joint during the coordinated wrist and hand movements.

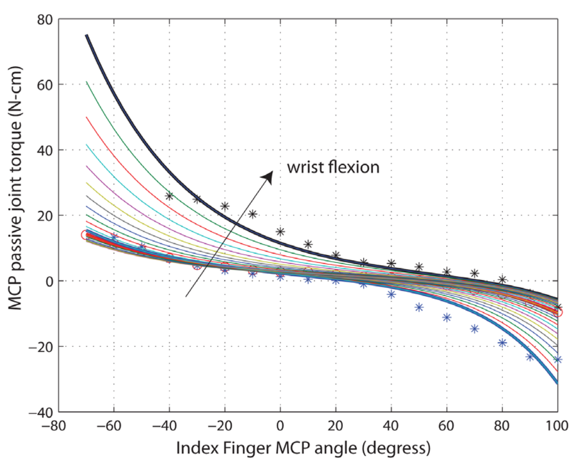

Figure 1: Variations in MCP passive torque for different finger and joint angles

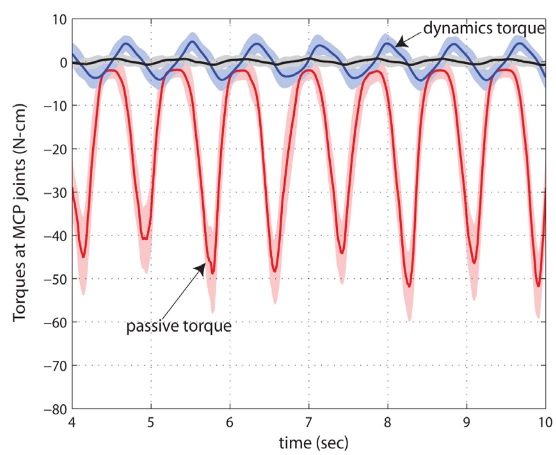

Figure 2: Contributions to MCP joint torques during coordinated finger-wrist movements

We conducted experiments with human subjects to model passive dynamics in hands. Figure 1 shows the joint torque at the MCP joint of the index finger due to flexion-extension of the finger. Different curves in the figure show variations in the MCP passive torques for different wrist angles. To generate these curves the subjects were asked to hold their finger at various angles and joint torques were calculated using force sensors. Figure 2 shows the variations in the contributions to the MCP joint torques by passive and dynamics toques during coordinated wrist and finger movements. To generate these curves the subjects were asked to move the finger and wrist in a coordinated fashion, and motion and force data was collected.

Figure 1 demonstrates that the passive torque contributions depend on the configurations of the finger and wrist. As the fingers and wrist move the tendons slide thus the passive muscle forces are translated uniquely at each finger-wrist configuration. Such a variation in passive torque contributions leads to specific regions of stability in the hand configuration space which must play an important role in the control of the fingers during object grasping and manipulation.

Figure 2 demonstrates that the contributions by the passive torques are much more dominant than the contributions by dynamics torques during coordinated wrist and finger movements. This is opposite of what is previously determined for coordinated experiments with other joints such as shoulder and elbow joints. Thus passive dynamics plays uniquely dominant role in hand control. Modeling and analysis of passive hand dynamics during various grasping and manipulations activities will lead to a better understanding of human hand controls, and also in new design and controls schemes for robotic hands.