IMPLEMENTING DATA-DRIVEN MODELS OF THE HUMAN THUMB INTO A ROBOTIC GRASP SIMULATOR TO PREDICT GRASP STABILITY

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INTRODUCTION

What are the features of the human hand that enable dexterous manipulation functionality that transcends that of state-of-the-art robotic hands? Understanding and emulating the biologically evolved solutions to the manipulation problem in humans would empower both biomechanists and roboticists alike. In this interdisciplinary work, we present the computational foundations to simulate and predict the functional advantages of multi-finger grasps with a biomechanically realistic model of the human hand.

METHODS

We translated the anatomical description of the “virtual five-link” thumb kinematics into a standard robotics notation (Denavit-Hartenberg (D-H)) using 3D geometry and D-H conventions [1]. We added musculoskeletal parameters (e.g., moment arms) to the kinematics, resulting in a 50-parameter robotics-based model capable of producing thumbtip forces and torques. We then used Markov Chain Monte Carlo simulations to find parameters that achieved a least squares best fit to experimental thumbtip forces [2].

As a first approximation, we implemented these best fit D-H parameters for the thumb in *GraspIt*! [3], our visualization and simulation engine designed for the study of grasp planning in robotic hands. The other fingers were simulated using universal joints at the metacarpophalangeal joints, and simple hinges at the interphalangeal joints [4]. With this program, grasps of arbitrary objects can be dynamically simulated, optimized for grasp stability, and objectively quantified for feasibility and grasp quality.

To quantify grasp quality, we use a robotics-based mathematical representation of grasp that employs a “grasp matrix” to relate fingertip contact forces (and torques if using soft fingertips) to the effective force and torque on the grasped object (the grasp “wrench”). The rank of the grasp matrix, for given object geometry and friction characteristics, is affected by fingertip placement and the margin of error permitted by the friction cones associated with each fingertip contact force, and is a measure of how many degrees of freedom of the object can be controlled [5]. We evaluate the ability of a quasi-static grasp to reject disturbances by building the 6D space of forces and torques that can be applied by the grasp using convex hull theory. We propose the hyper-volume of this space as one possible measure of grasp quality, since a larger volume of this space means that the grasp is more efficient at rejecting force and torque perturbations [3].

RESULTS AND DISCUSSION

The D-H representation of the anatomy-based, non-intersecting, non-orthogonal axes of rotation for the thumb provides a new biomimetic direction for comparative kinematic studies of robotic and human hands, and may help elucidate whether and how these kinematic features enable dexterous manipulation in humans (Fig. 1). Traditionally, simple orthogonal axes of rotation are used to model thumb kinematics in robotic hands, but our work suggests these articulations cannot realistically predict 3D static thumbtip forces [6].

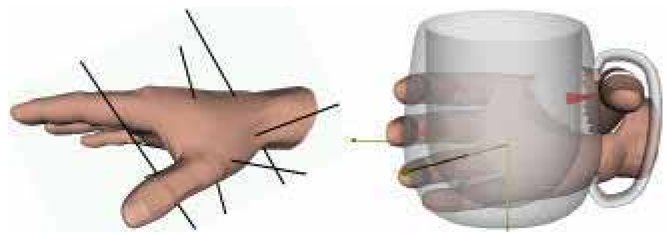

Figure 1: Left: The anatomy-based model represents more faithfully the thumb’s five non-orthogonal, non-intersecting joint axes. Right: The hand model grasps a mug.

We have adapted a computational environment to quantify grasp quality of biomimetic human hands. Our critical challenge now is to determine the level of model complexity that is necessary and sufficient for predicting realistic multi-finger manipulation function. We are currently investigating adaptive refinement finite element methods to account for finger pad compliance and skin deformation, tendon interconnections within and across fingers, and will use accurate skeletal geometry to constrain the innermost elements. This computational platform will allow us to investigate the relative contributions of passive anatomical elements and active neuromuscular elements to dexterous manipulation.

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