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Under-actuated Prosthetic Hand Literature Review

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Mechanical Requirements

In order to meet the comprehensive engineering requirements of marketable human hand prostheses, numerous factors must be considered. An optimal hand would balance low mass, achieve substantial gripping force and dexterity, and feature object-based grip sensitivity (while keeping accounting for material cost and longevity). To lower the torque requirements for the upper components of the prosthetic arm, the mass of the under-actuated hand mechanism will be limited to a maximum of 502g [1.1 lbm], which is the mean mass of a male human hand (Winter, 1990). The hand will have a feature a 100 N [22.5 lbf] gripping force in order to match the grasping force of commercial prosthetic hands, such as the Ottobock MyoHand VariPlus Speed (Ottobock, 2012). The hand must also be able to pick up a minimum payload weight of 2 kg [4.4 lbm] (Meijneke et al, 2011).

To demonstrate the dexterity and functionality of the under-actuated mechanism, seven objects have been chosen as metrics for the hand's performance. The items and justification for choosing them are listed in the table below:

Item	**Justification**
Grape	Demonstrates that the hand can grasp objects delicately
Baseball	Demonstrates that the hand can grasp spherical objects
Water bottle	Demonstrates that the hand can grasp cylindrical objects
Snack food box	Demonstrates that the hand can grasp prismatic objects
Cable	Demonstrates that the hand can grasp fine objects
Erlenmeyer flask	Demonstrates that the hand can grasp delicate, oblong, low-friction objects.
Spray bottle	Demonstrates that the hand can actuate objects such as a trigger

Concepts from Prior Work

Due to the actuation constraints surrounding this project, fingers present the most difficult engineering challenge. In their 2008 paper "An Anthropomorphic Underactuated Robotic Hand with 15 Dofs and a Single Actuator," Gosselin et al. point out that having an anthropomorphic hand (i.e. one with fingers similar to the human hand) will result in greater grasping capability with simpler implementation. Compared to other prosthetic anthropomorphic hands with clutches and complex linkages, an underactuated mechanism with a single actuator will also result in a simpler overall design. In the 2012 book "Automation in Warehouse Development" a chapter entitled "Underactuated Robotic Hands for Grasping in Warehouses" by Kragten et al. confirms that an underactuated hand would result in a "cheap, robust, and a reliably grasping [hand]" (Kragten et al., 2012). However, one of the key pieces of information in Gosselin et al.'s paper is the data that underactuated fingers will result in a loss of efficiency. They highlight that an actuation force of 100 N [22.5 lbf] would result in a grasping force of only approximately 28 N [6.3 lbf]. With this efficiency ratio in mind, the actuating motor design will need to account for any losses, with the calculations based on simple free body diagrams and force approximations.

Tools and Opportunities from Prior Work

In order to minimize work requirements up the arm, it is critical that the mass of the prosthetic hand be as small as possible; the higher the mass of the hand, the higher the inertial loads that need to be overcome up the line. Therefore, previously implemented data was considered for the target mass. The 50% percentile male hand has a mass of 502 g [1.1 lbf] (Frederick, 2012), while existing designs call for a mass under 500 g [1.1 lbf] (Light et al, 2000). The proposed five-finger design, as opposed to three-fingered under-actuated hands, will mimic a human hand for aesthetic appeal and will feature comparable finger link lengths. The “Golden Section” rule calculated the distal, medial, and proximal link lengths to be 1.75, 2.84, and 4.57 cm [0.69, 1.12, and 1.8 in], respectively (Nasser et al, 2006). This biomimetic methodology will be applied during the design phase, and will incorporate the thumb, which has only two links: proximal and distal. The proposed design must be capable of picking up a variety of objects, thus an appropriate clamping force of 22.5 lbf [100 N] will be used based on pre-existing data (Otto Bock, 2012). The clamping force, hand geometry, and contact friction will enable the lifting of objects, as can be seen by the data provided which highlights that a 4.4 lbm [2 kg] object can be lifted given a 0.36 friction coefficient (Meijneke et al, 2011).

Considering existing hand designs to date, the use of specific material remains untouched, with no clear trend. Likely the usable material bank will include aluminum, printed or stock ABS, or perhaps resin-hard composite materials like fiberglass or carbon fiber. All of these materials, while each unique in mechanical merit, lie on the light end of the material spectrum and will be useful in this application.

SolidWorks, MATLAB and ANSYS will be used during the design of this prosthetic hand. SolidWorks, both readily available and wildly popular, is used not only as a three-dimensional modeling software, but also as a tool to run analyses, make engineering drawings, and easily share work and design ideas with other prosthetic arm groups. MATLAB, a powerful mathematical tool, along with its integrated dynamic simulation constituent, Simulink, will be used for a kinematic analysis based on the mathematic model of the prosthetic hand, leading the team to a deeper understanding of the whole system. ANSYS will be used to further analyze the dynamic performance of the prosthetic hand, including stress-strain analysis, modal analysis and so forth.

Overview of Planned Methods

In the duration of this design process, the team will simultaneously be following a tried-and-true schedule for designing, prototyping and testing the product, and working with other groups to ensure the full and effective integration of the hand into the prosthetic arm assembly. All members bring a variety of talents and skills to the team, which is critical in obtaining a feasible design goal. The end-product will require not only quality components, but smooth integration between all parts with error-reducing redundancy. The schedule consists of: initial design and hand calculations, solid modeling using CAD software, rapid prototyping, integration and development with other teams, secondary prototyping and refinement of CAD, preliminary dynamic simulation, tertiary CAD refinement, beta prototype, physical testing and integration, alpha prototyping and finalization. Given project nature, minor deviations from this plan are expected, though the team will maintain focus on the schedule and goals.

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