AN OPTIMIZED SOLUTION TO THE GRASPING PROBLEM: THE FITNESS OF THE HUMAN HAND

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INTRODUCTION

There is great debate about how effectively the human hand is able to grasp and manipulate objects and whether it is optimized in any sense. Here we compare the grasping capabilities of the physiological human hand and *thousands* of tendon-driven anthropomorphic hand designs under the same constraints as the human hands: size, sum of muscle tensions, and D-H parameters.

METHODS

We use a previously-developed method to calculate the grasp quality of the human hand and anthropomorphic tendon-driven hands [1,2]. Briefly, the grasp quality is the maximal force or torque (scaled with the size of the object) which the grasp can exert. A higher grasp quality indicates a stronger grasp.

We used the kinematic layout (i.e., DH-parameters) of the commercially-available Shadow Hand (an anthropomorphic robotic hand) when calculating grasp quality for robotic hand designs, and human hand grasp quality was calculated from previously-published cadaveric data [3,4].

We used a Monte Carlo search to obtain randomized tendon routings for 4000 robotic hands and calculated the resulting grasp quality. We subsequently optimized the joint centers of rotation for the hands with a custom greedy Markov-Chain Monte Carlo method, which was our first optimization step. We then optimized the distribution of maximal tendon tensions using a similar method, our second optimization step.

RESULTS

The grasp qualities for the random tendon routings which were unoptimized in joint center of rotation and maximal tendon tension distribution are shown in Figure 1, as well as the grasp qualities following the optimization steps. We see that none of the unoptimized designs can outperform the human hand in grasp quality, and that optimized designs can indeed outperform the human hand (for this grasping task). We also see that the best hand design outperforms the naïve design (a symmetric routing with one tendon on each side of every joint) by 501%.

DISCUSSION & CONCLUSIONS

We conclude that the human hand has critical morphological features lending it very good grasp capabilities. These include specific distributions of maximal muscle tensions (some muscles are much stronger than others) and moment arm ratios, and the centers of rotation away from the midline of joints (typically giving way to larger moment arms on the flexion side).

REFERENCES

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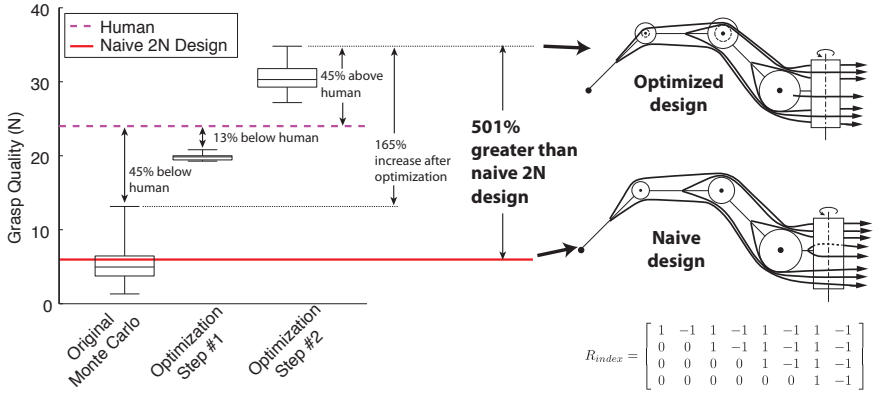

Figure 1: Grasp quality results from random designs (Original Monte Carlo), optimized designs, and the human hand. Index finger only of robotic hands shown. Maximal tendon tension distribution not shown.