Quantitative Comparison of Grasp Qualities of Two Tendon-driven Hands Using a Novel Methodology

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Abstract:
While there is great interest in designing and controlling biologically-inspired, tendon-driven robotic hands, we have lacked computational methodologies to evaluate and refine alternative topologies based on objective grasp metrics. We have overcome this obstacle by employing computational geometry to find the full set of feasible grasp wrenches and the corresponding grasp quality metrics for a collection of fingers driven by multiple tendons with arbitrary routing and maximal tensions. We present this analysis for two- and three-finger grasps performed by three-dimensional fingers, each with 4 kinematic degrees of freedom (DOFs, one ad-abduction and three flexion-extension joints).

Introduction:
Biologically-inspired tendon-driven systems have been designed for the past few decades for the purposes of grasping and manipulation [1]. These systems have distinct advantages over torque-driven systems including light weight, low backlash, small size, high speed, remote actuation, and significant *design flexibility* in setting moment arms and maximal tendon tensions [2]. This allows optimization of system output capabilities for a particular task.

Here we demonstrate a comprehensive technique for computing the full set of feasible grasp wrenches for arbitrary tendon-driven finger topology and grasp configuration, allowing the calculation of grasp quality metrics. We present comparisons of grasp quality for two different tendon-driven finger topologies and two grasp configurations.

Methods:
The tendon layouts analyzed are shown in Figure 1. The link lengths were 2cm and all moment arms were 5mm. Figure 1a shows a "2N" design which has 8 tendons (N is the number of DOFs) and Figure 1b shows an "N+1" design which has 5 tendons. The maximal tendon tension sum is 1000N, which is divided up evenly among the tendons for each finger.

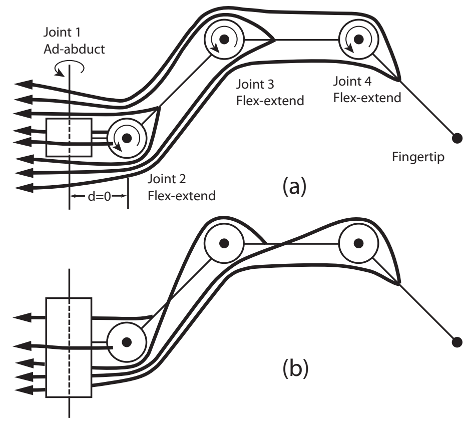

Figure 1: Tendon layouts analyzed. (a) 2N design. (b) N+1 design.

The fingertip force-production capabilities for these two designs are determined by calculating the feasible force set, which is a function of tendon layout [3]. After the feasible force sets are calculated, they are intersected with friction cones in order to produce a feasible object force set. This set represents the forces that can be applied to the object by the fingertip, and it is illustrated in Figure 2.

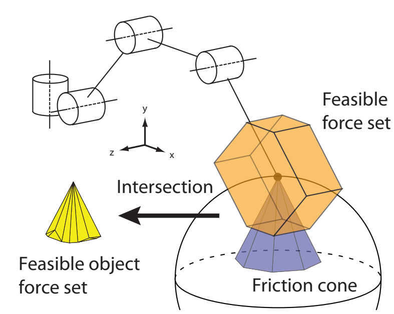

Figure 2: Feasible force set intersected with friction cone.

The feasible object force set is calculated for each finger, using placements shown in Figure 3. These sets are used to determine all the forces and torques that can be resisted in 6-dimensional wrench space (i.e., 3 force dimensions and 3 torque dimensions) [4].

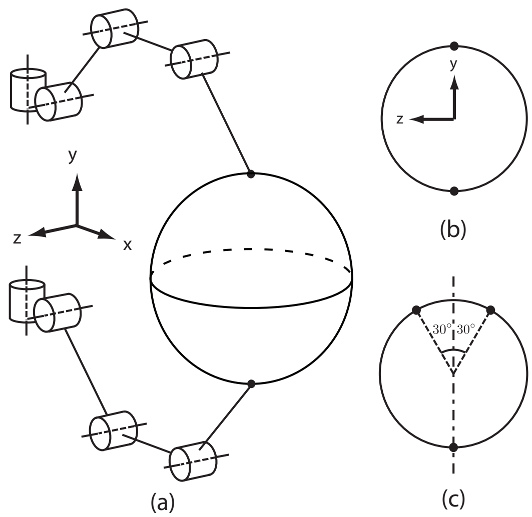

Figure 3: Grasp configurations analyzed. (a) Isometric view of 2-finger grasp. (b) Front view of 2-finger grasp. (c) Front view of 3-finger grasp.

Two metrics of grasp quality can then be determined from this 6-D set. The first, which we call the *characteristic length*, is based on the volume of the set, and is calculated using the following formula:

$$Characteristic\ Length = \left(\frac{6V}{\pi^3}\right)^{1/6}$$

This is a linear measure that is equal to the radius of the 6-D ball with the same volume as the 6-D set.

The second metric is the *radius of the largest ball*, centered at the origin, that the 6-D set can contain. This is the "weakest wrench magnitude" that can be resisted by the grasp [4].

Results:

The results for each tendon layout and grasp configuration are shown in the table below.

	2N Design	N+1 Design
2-finger	15.1/2.59	11.3/1.71
3-finger	30.1/8.66	24.5/5.60

Table 1: Grasp quality results. Units are in Newtons and numbers are Characteristic Length/Radius of Largest Ball.

We see that the 2N design outperforms the N+1 design and that 3-finger grasps outperform 2-finger grasps.

Discussion:

While the fact that 3-finger grasps outperform 2-finger grasps is not surprising, the fact that this 2N design outperforms this N+1 design, while having the same sum of maximal tendon tensions, is not immediately obvious or necessarily intuitive. This method allows calculation of the grasp quality of *any* tendon layout, maximal tendon tension distribution, moment arm values, and link lengths, which will enable the use of optimization techniques in later studies.

Computational speed and efficiency are important issues to address with our methodology if optimization is to be performed (the evaluations took around 5 seconds to complete for each configuration).

References:

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