Novel Dexterous Robotic Finger Concept with Controlled Stiffness

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1 Introduction

These days, robotic research is shifting focus towards robots for applications in human environments. This can be either robots for household tasks as well as flexible robots for unstructured and diverse industrial tasks. Many of these tasks deal with object grasping (and releasing) and object manipulation, while often interacting with some environment as done by our human hands.

The challenge is to develop a robotic hand that can execute the unstructured and varying hand tasks as well as deal with a wide variety of object shapes and materials. The human hand uses its dexterity for manipulability and to be flexible w.r.t. (object) shapes. Furthermore, the human fingers possess adjustable stiffness. This research project aims to develop a robotic hand based on the here presented novel robotic finger concept that resembles the dexterity and controlled stiffness properties of the human hand. The adjustable mechanical stiffness allows to adapt the mechanics (without relying on high bandwidth feedback control loops) for either force (e.g. grasping) or position (e.g. manipulation) sensitive tasks or combinations of the two.

Current state of the art presents robotic hands that have full dof control at the cost of controller and design complexity, reliability and costly components, e.g the DLR Hand [1]. Also under-actuated hands are found, based on the well known 'Soft Gripper' [2]. The under-actuated coupled mechanism naturally adapts to object shapes. Hence, at the cost of controlled stiffness and dexterity, this concept can easily handle a wide variety of object shapes, without requiring complex control strategies.

2 Novel Grasper Concept

Figure 1 presents our novel robotic finger concept. The concept combines 3 key features: 1- a coupled antagonistic under-actuated tendon driving mechanism, 2- series elastic tendon actuation with non-linear springs and 3- active joint locking mechanisms on the joints. The under-actuated principles are used to reduce control complexity, while keeping dexterity (by modulating the joint locks) and introducing controlled mechanical stiffness.

The relative position of x_1, x_2 determines the equilibrium (no external force) finger configuration space Q_e, i.e. all $\bar{q} \in Q_e$ that minimize the potential energy ($E(x_1, x_2, \bar{q})$) of the unconstrained finger:

$$\frac{\partial E}{\partial \bar{x}} = 0 \quad \Rightarrow \quad (x_1, x_2, \bar{q} \in Q_e) \qquad (1)$$

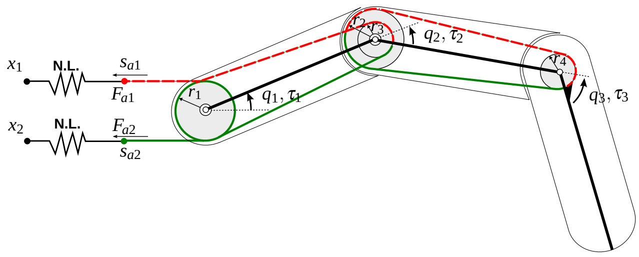

Figure 1: Novel robotic finger concept (*N.L.* = non-linear spring, $\bar{q} = (q_1, q_2, q_3)$). Pulley 1, 2 rotate freely on joint axes. Pulley 3 is fixed to 3^{rd} phalanx. Joint locks can be switched on to constrain the relative motion of the two attached phalanxes.

Also the apparent mechanical stiffness is a function of the positions x_1, x_2. Choosing two proper and identical non-linear spring functions makes sure that with x_1, x_2 both the stiffness and Q_e can be set without interfering.

Grasping is executed in 2 stages; *pre-shaping* and *object fixturing*. Pre-shaping (and finger manipulation) is done by moving x_1, x_2 *and* modulating the joint locks, s.t. the finger moves to a desired configuration $\bar{q}_p \in Q_e$ without getting in contact with the object. Then the object can be fixtured by moving x_1, x_2, s.t. Q_e changes. If Q_e is chosen properly, the phalanxes will move to, but not reach, Q_e. Instead, the phalanxes naturally adapt their configuration around the object. The resulting contact forces follow from the deviation of the established constrained finger configuration w.r.t. Q_e and the preset mechanical stiffness.

Hence, the finger is controlled by simple low bandwidth position control for x_1, x_2 and joint lock modulation. Only angular position sensors are needed to measure $\bar{q}$ and derive $\bar{\tau}$. Modeling and control of the novel finger for robotic grasping will be the topic of the presentation.

References

[1] J. Butterfaß, M. Grebenstein, H. Liu, and G. Hirzinger, "Dlr-hand ii: Next generation of a dextrous robot hand," in *IEEE International Conference on Robotics and Automation*, 2001, pp. 109–114.

[2] S. Hirose and Y. Umetani, "The development of soft gripper for the versatile robot hand," *Mechanism and Machine Theory*, vol. 13, pp. 351–359, 1978.

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