Elastic Transmission Mechanisms: Multiport Models for Human-like Compliant Grasping in Robotic Hands

THE UNIVERSITY of TULSA
Department of Mechanical Engineering

Joshua A. Schultz[1], Michael J. Martell[1] and Gavin O'Mahony[2]

OU Medicine

[1]Department of Mechanical Engineering, the University of Tulsa
[2]Department of Orthopedic Surgery and Rehabilitation, the University of Oklahoma Health Sciences Center

Background and Motivation

- A gap exists between the mathematical tools of robotic grasp theory - which begins at the contact points with an object – and human grasping, the analysis of which begins at muscle activation
- A linear compliance model, which can mechanically enforce a prescribed actuator/finger tendon relationship by an elastic transmission element, can bridge these two areas, enabling the design of a robotic hand that possesses the advantages of a human way of grasping

Finger Individuation and Coupling in Human Grasping

- Some motor units in the human hand can apply force individually to a single digit to produce an isolated and independent movement, while others act in unison on multiple digits at once, coupling their motion
- **Individuation:** The flexor digitorum profundus tendon to the index finger has a distinct muscle belly, which enables independent joint flexion. Also, the adduction/abduction of each finger is produced by the intrinsic muscles, which have no interdigital connections
- **Coupling:** Substantial linkage between the extensor digitorum communis tendons between the ring and middle fingers makes it difficult to impossible to produce independent extension of either finger while the other is held flexed

Postural Synergies

- Coordinated motions of hand joints (Fig. 1)
- Combinations of these motion patterns comprise a grasp posture

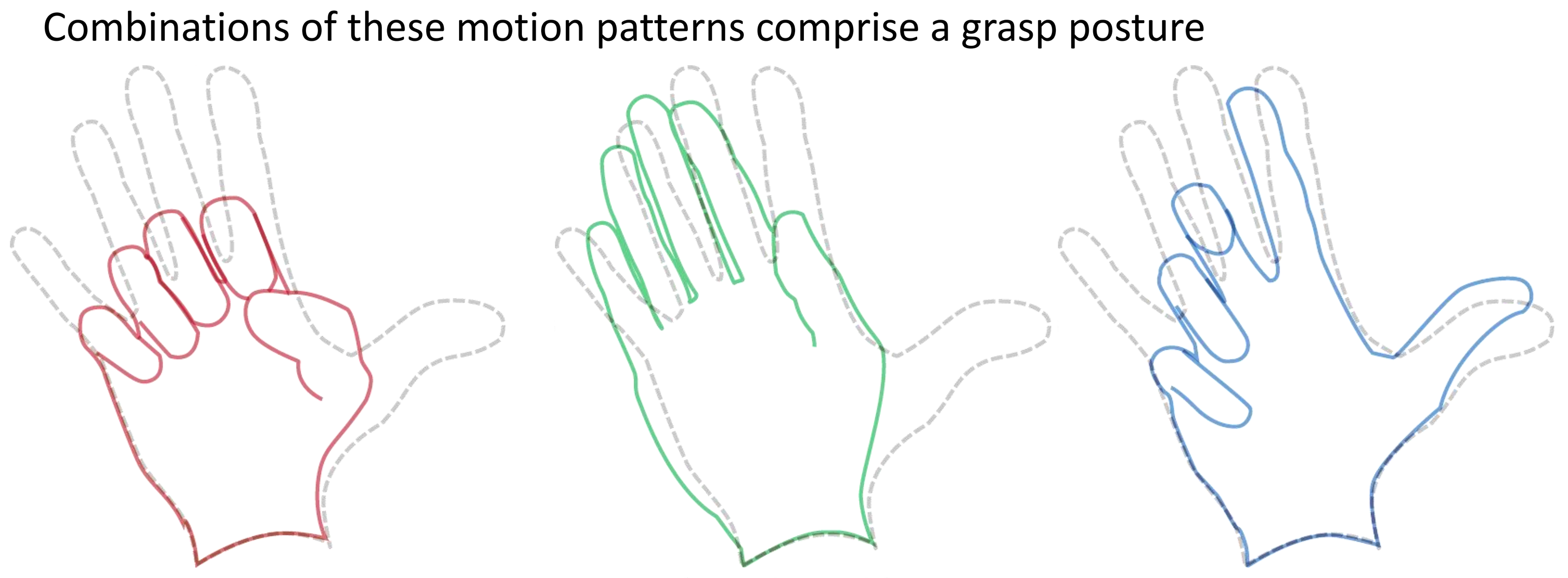
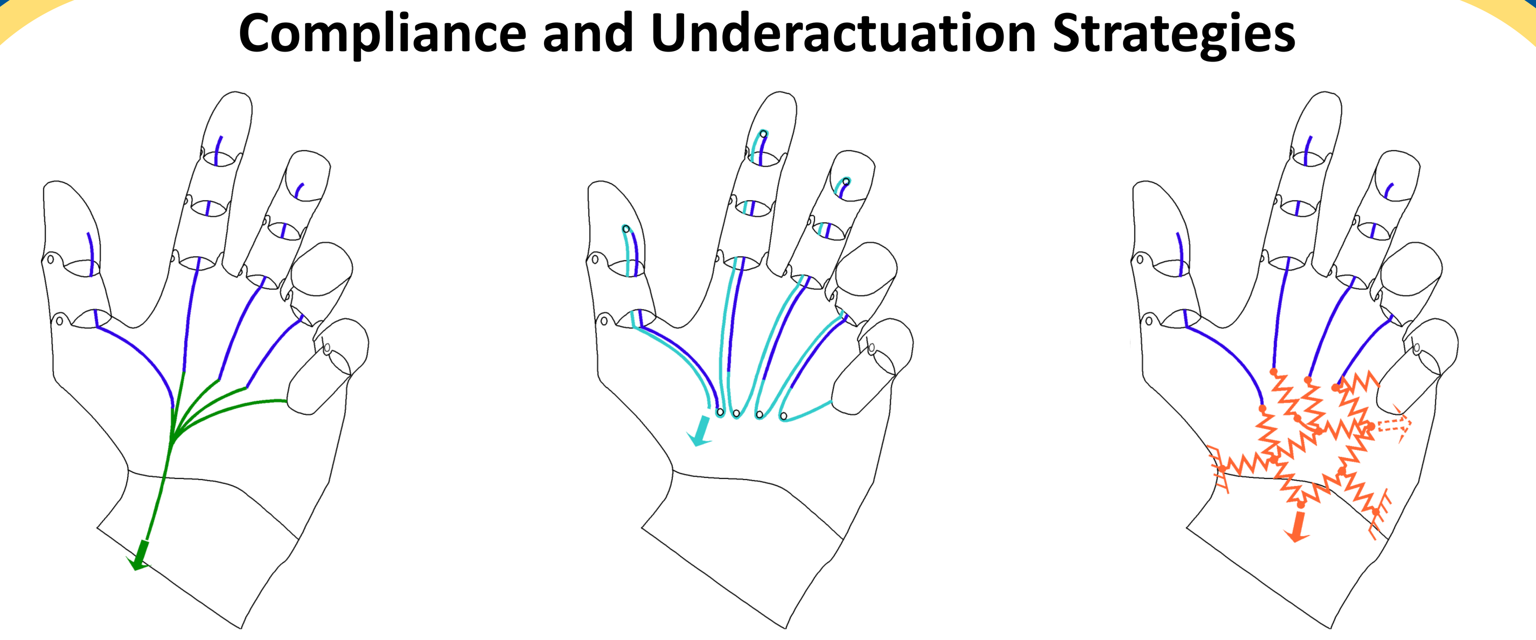


Fig. 1. Examples of coordinated finger joint motion

Compliance and Underactuation Strategies



(a) "Branched" connection (b) "Cable circuit" connection (c) Elastic transmission mechanism

Fig. 2. Underactuation strategies

- Compliance in a robotic hand design allows it to conform to an object of uncertain size and shape, removing the need for exact certainty in planning a grasp
- An underactuated robotic hand has fewer actuators than tendons
- Underactuation is an advantageous strategy for reducing the weight and complexity of a grasping device
- Underactuated grasping with a single actuator can be accomplished with the branched and cable circuit strategies of Fig. 2 (a) and (b)
- Extending underactuation from one to multiple actuators is not straightforward, and we propose a mathematical framework that describes mapping of actuator displacement to tendon force. An elastic transmission mechanism, pictured in Fig. 2 (c), transmits actuator force and displacement to the finger tendons

The University of Tulsa Hand

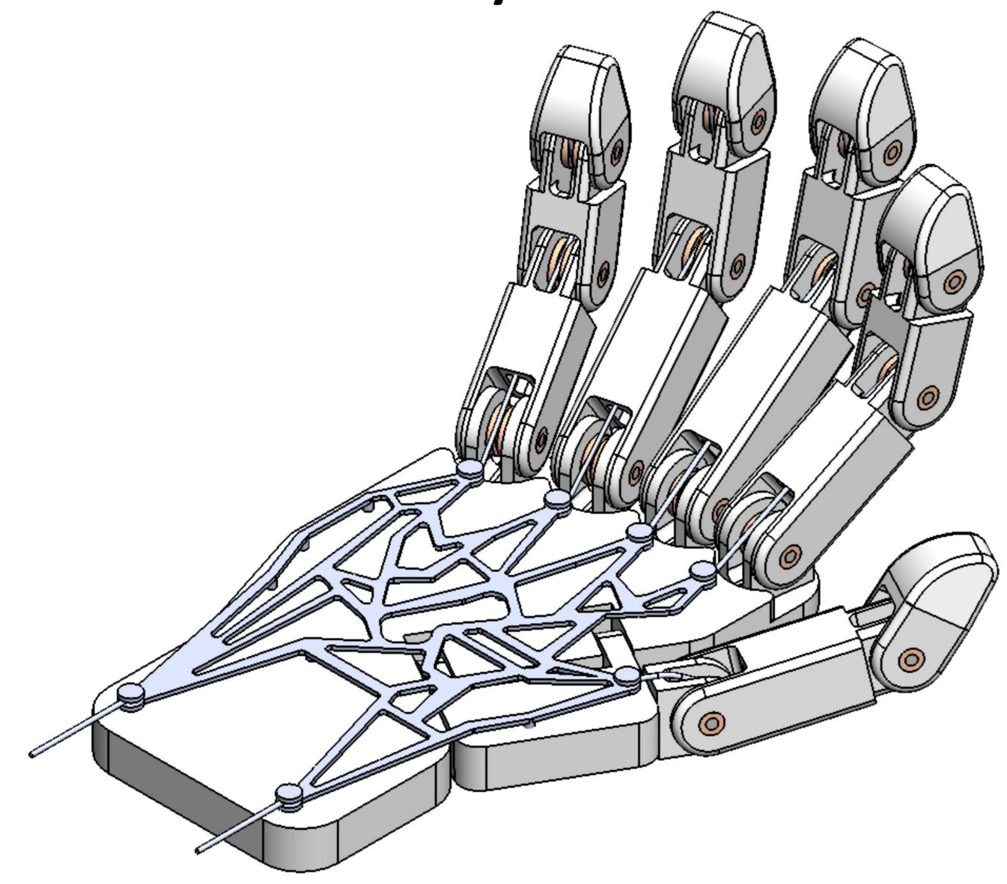


Fig. 3. The University of Tulsa (TU) Hand, a multiple-synergy compliant hand

- Underactuated hand with two synergies, each controlled by one of two extrinsic actuators
- Capable of achieving a wider variety of useful postures than single synergy hands
- Actuator force and displacement is transmitted through an elastic element, or compliant web, to a biologically-inspired system of finger tendons
- Advantages include low weight, compactness, and simplicity, making it potentially suitable for a prosthetic device
- Variety of postures from its two synergies and physical compliance allows the hand to conform to a variety of objects

Multiport Network Modeling and the Elastic Transmission Mechanism

- The relationship between force and displacement of a compliant mechanism can be modeled using a multi-port network (Fig. 4), a concept from circuit theory to accurately and concisely describe a complicated system's input-output behavior
- Elastic transmission element, or web, will be built up of small, interconnected compliant mechanisms
- Force and displacement characteristics of the entire web will be assigned, first by modeling each constituent element's force and displacement characteristics, then considering their connections

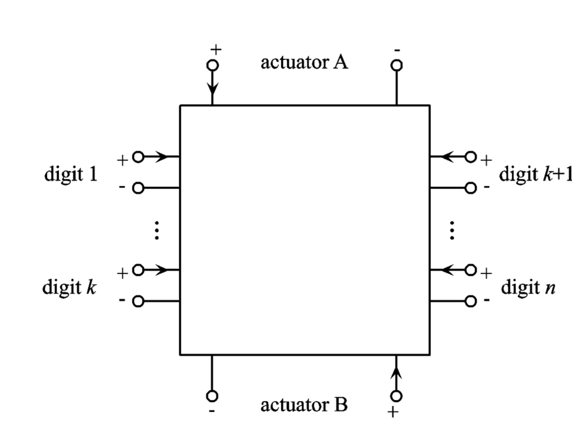


Fig. 4. Multiport network

- Any interconnection of compliant mechanisms in series or parallel has been proven to be positive definite[1], which indicates that a grasp will be stable
- The mapping from actuator to finger tendons is formulated in (1), where F_j is the force corresponding to each finger tendon or actuator, and δ_j is its displacement

$$\begin{bmatrix} F_1 \\ \vdots \\ F_n \\ \hline \delta_1 \\ \vdots \\ \delta_n \end{bmatrix} = \Lambda \begin{bmatrix} F_{n+1} \\ \vdots \\ F_{n+m} \\ \hline \delta_{n+1} \\ \vdots \\ \delta_{n+m} \end{bmatrix} + \gamma = \left[\begin{array}{c|c} \Lambda_{11} & \Lambda_{12} \\ \hline \Lambda_{21} & \Lambda_{22} \end{array} \right] \begin{bmatrix} F_{n+1} \\ \vdots \\ F_{n+m} \\ \hline \delta_{n+1} \\ \vdots \\ \delta_{n+m} \end{bmatrix} + \gamma \qquad (1)$$

[1]M. Martell and J. Schultz, "Multiport Modeling of Force and Displacement in Elastic Transmissions for Underactuated Hands," *IROS 2014*

Future Work

- Experimental validation of multiport network modeling with a planar 3-digit grasping mechanism
- Mathematical model of relationship between finger tendon displacement and finger joint angle (Fig. 5)
- Mathematical model of stiffness matrix for the compliant web
- Completion and testing of the TU Hand (Fig. 3)

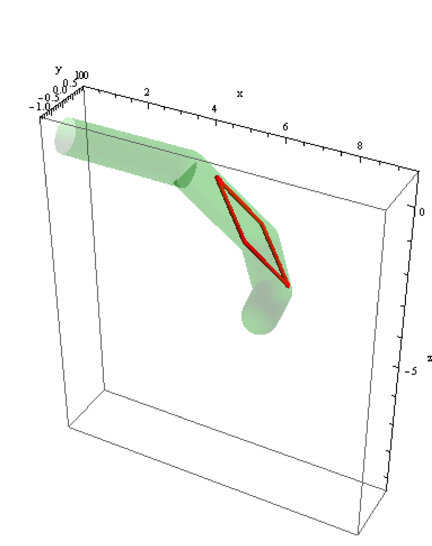


Fig. 5. Rhomboidal model of the extensor hood

Biological Robotics at Tulsa Lab Website

http://personal.utulsa.edu/~jas019/