Special Issue on the Mechanics and Design of Robotic Hands

There has been a renewed interest in recent years to work towards robotic hands that are effective in addressing the needs of modern robotic systems. As robots increasingly move out of the lab and into unstructured environments, the need for hands designed to function under the uncertainty and wide range of conditions associated with those environments has become more pressing. This special issue focuses on papers that address the mechanics and practical design requirements associated with current grasping and manipulation applications, including systems that are lightweight, dexterous, mobile-friendly, inexpensive, robust to uncertainty, and durable.

This special issue consists of nine papers from researchers around the globe. The scope of the papers spans a wide spectrum of approaches, from underactuated hands with a single or small number of actuators, to fully actuated hands with nearly human-like controllable degrees of freedom. A number of the hands incorporate some novel design feature that has yet to be examined in the context of robotic hands, including electrostatic clutches, twisted-string actuators, or novel underactuated mechanisms. Two of the hands present modular designs, with multiple uses of the same actuation module, and three of the hands attempt to achieve close anthropomorphism.

Before getting to the papers that present complete hand designs, we begin the issue with two papers that focus on tendon-based actuation in robotic fingers. In Shirafuji, Ikemoto, and Hosoda, researchers from Osaka University examine the design of a tendon-driven finger modeled after the human index finger. Their design includes a mechanism to change the moment arm of tendons, as well as using branching tendons in order to mimic some of the features of the human finger.

The second paper describes work by Inouye and Valero-Cuevas of the University of Southern California on the optimization of tendon routing in robotic fingers. By examining variations in asymmetry in joint centers, tendon routings, and maximal tendon tensions, among other parameters, they show that optimum tendon routing can produce fingers with force-production capabilities that can exceed that of human hands.

The next three papers present the three hands developed under the US's Defense Advanced Research Projects Agency (DARPA) Autonomous Robotic Manipulation (ARM) program. While a large portion of the program focused on research involving developing algorithms and software for an existing robotic platform (i.e. the “software track”), three “hardware track” teams were selected to develop new robotic hands, which are described in this Special Issue. Two of the hands, described by Quigley, Salisbury, Ng, and Salisbury and Odhner, Jentoft, Claffee, Corson, Tenzer, Ma, Buehler, Kohout, Howe, and Dollar are also being utilized in the DARPA Robotics Challenge, mounted on the full-scale Atlas humanoid robots developed by Boston Dynamics.

The first DARPA ARM paper, by Quigley et al., describes work by a team involving researchers from Sandia National Laboratories and Stanford University. They present a modular design, in which a “thumb” and three “fingers” are built from identical modules arranged around a base palm.

The next two papers from the DARPA ARM program, as well as the two papers following them, present various underactuated hand morphologies. The paper by Aukes, Heyenmann, Ulmen, Stuart, Cutkosky, Kim Garcia, and Edsinger involves a team from SRI International, Stanford University, and Meka Robotics. Their design takes advantage of electrostatic brakes to selectively lock and unlock the finger joints, adding structural stability for larger grasp forces and allowing for selection of various actuation schemes for the otherwise underactuated design.

The final DARPA ARM hand is described in the paper by Odhner et al., involving a team from iRobot, Harvard, and Yale. They present a compliant and underactuated hand with five actuators, designed to enable an adaptive power grasp, precision pinch grasping, and a limited amount of dexterous, within-hand manipulation.

The first of two additional underactuated hand designs is presented in Ciocarlie, Hicks, Holmberg, Hawke, Schlacht, Gee, Stanford, and Bahadur by a team of researchers formerly at Willow Garage. The two-fingered hand is driven by a single actuator, and incorporates a mechanism that keeps the distal phalanges parallel during opening and closing for precision grasps, and is decoupled during power grasps for better wrapping contacts on the object.

The final underactuated hand in the issue is described in Catalano, Grioli, Farnioli, Serio, Piazza, and Bicchi by a team of researchers from the University of Pisa and the Istituto Italiano di Tecnologia, Genova. The
anthropomorphic hand is designed to incorporate “adaptive synergies”, utilizes a single actuation input routed to all joints of the hand, and includes an interesting ligament-constrained joint design.

The final two papers present two additional fully actuated hand designs. A second modular hand design is described by Martin and Grossard from Centro Universitario de la Defensa, Zaragoza, Spain, and CEA LIST, France. Their approach involves a 20 degrees-of-freedom anthropomorphic hand that prioritizes backdrivability of the actuators.

Finally, Palli, Melchiorri, Vassura, Scarcia, Berselli, Cavallo, De Maria, Natale, Pirozzi, May, Ficuciello, and Siciliano describe work by a team from Bologna, Napoli, and Saarland on the DEXMART project. Their hand is also anthropomorphic, and incorporates “twisted-string” transmissions and a number of optical tactile and proprioceptive sensors integrated into the hand structure.

While dexterous autonomous robotic manipulation still requires a number of advances in order to be robustly implemented on practical systems, we believe that recent progress in robotic hand hardware, including advances described in this special issue, has helped to put those capabilities within closer reach.

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