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PHASEHAND: DESIGN OF AN UNDERACTUATED GRASP CHANGING ROBOT HAND

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ABSTRACT

Robotic hands often incorporate multiple grasping capabilities to handle objects of various sizes and shapes. However, switching between grasp types (mode switching) typically requires an additional degree of actuation, increasing complexity, execution time, and the control burden of selecting the desirable mode. This paper presents the design of the PhaseHand, an underactuated, three-fingered adaptive gripper that can sequentially change its grasp type using a single actuator—without the need for sensors or external or higher level controls—thereby simplifying operation and reducing the likelihood of grasp failures. Underactuation is achieved through differential transmission mechanisms, allowing the fingers and hand to passively conform to the shape of an object, ensuring reliable performance without the need for complex computations. By integrating an underactuated swivel at the base of one of the three fingers, the hand can perform power, tripod, and pinch grasps, cycling through them sequentially via a careful balance of joint stiffness and friction. The gripper's functionality is demonstrated through benchtop grasp evaluations, highlighting its ability to adapt to diverse object geometries and transition between grasps without additional input. The design offers a low-cost, mechanically efficient solution for robotic manipulation tasks, with potential applications in assistive devices, industrial automation, and service robotics, and unstructured environments where simple, adaptable grasping is crucial.

Keywords: underactuation, grasping, design and control, prosthetics, differential, multifingered hands, robotics.

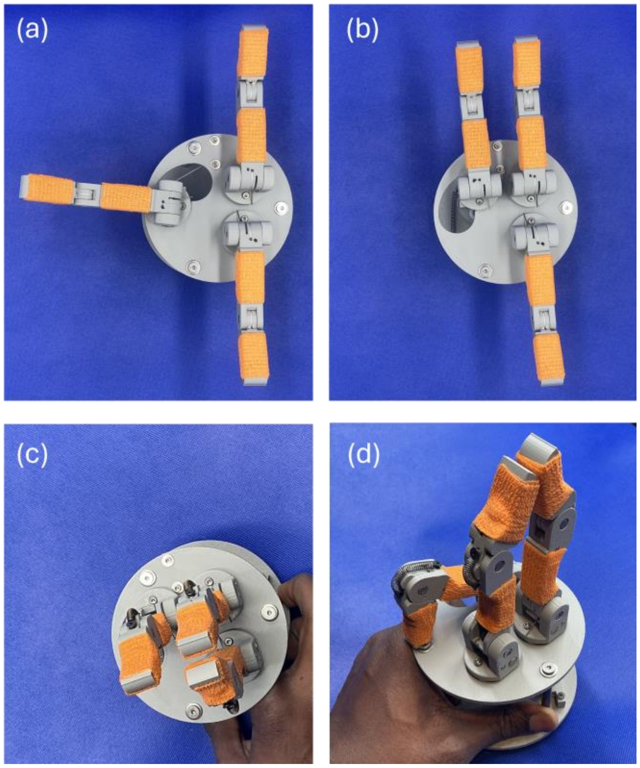

Figure 1. The sequential phases of the *PhaseHand*. The hand transitions from (a) fully open power grasp to (b) tripod grasp to (c) pinch grasp to (d) fully closed configuration.

1. INTRODUCTION

While simpler robotic grippers, such as suction-cup and parallel-jaw grippers, have demonstrated impressive manipulation capabilities [1,2], they are limited in their ability to perform the diverse range of tasks that the human hand can easily accomplish. Multi-fingered robotic hands offer greater dexterity and adaptability, enabling a broader set of grasping and manipulation strategies compared to simpler designs [3]. By performing a wider range of grasp types, multi-fingered hands can accommodate various object geometries, sizes, and functionalities. For example, a power-grasp can be used to grasp large cylindrical tools or objects, while precision grasps like tripod or later pinches are better suited to grasp smaller objects such as scissors or keys [4]. This has driven the development of highly articulated robotic hands, such as the Shadow Dexterous Hand [5], which closely mimics human hand function. However, this increased dexterity also comes with greater control complexity, requiring fine sensing and precise coordination of the additional degrees of freedom (DOFs) [6]. Beyond joint-level actuation strategies, grasp type selection itself remains an ongoing research challenge, with approaches leveraging computer vision algorithms to analyze object geometry and affordances to determine the most appropriate grasp strategy [7].

One approach to managing the complexity of multi-fingered robotic hands is underactuation, where the number of actuators is fewer than the number of controllable joints, relying on passive elements such as springs and compliant structures to achieve grasp closure [8]. In robotic hands, underactuation enables fingers to conform naturally to object surfaces, which may include finger-splaying [9], enhancing passive adaptability while simplifying control [10]. This design strategy is particularly advantageous for grasping irregular or unknown objects, where precise joint-level control may not be necessary [11].

Introducing underactuation between the fingers of a robotic hand allows for the reduced complexity of the systems, from the actuation point of view. The application of this principle has been demonstrated with several prototypes [12]. The basic element commonly used to this end is the differential mechanism. These types of mechanisms have been used extensively in robotic hands to enable passive adaptation to a wide range of object sizes, shapes, and positions/orientations in a purely open-loop manner [10] (examples can be seen in [13-17]).

Adaptive synergies extend this concept by modulating grasping behaviors, allowing underactuated hands to accommodate a wider range of objects and tasks [18]. However, while underactuated hands excel at passively conforming to object geometry [19], switching between grasp types remains an active task [20]. This limitation is especially significant in upper-limb prosthetics, where users must manually switch between grasp modes, whether in myoelectric [21] or body-powered [22] devices, making grasp transitions an ongoing challenge [23].

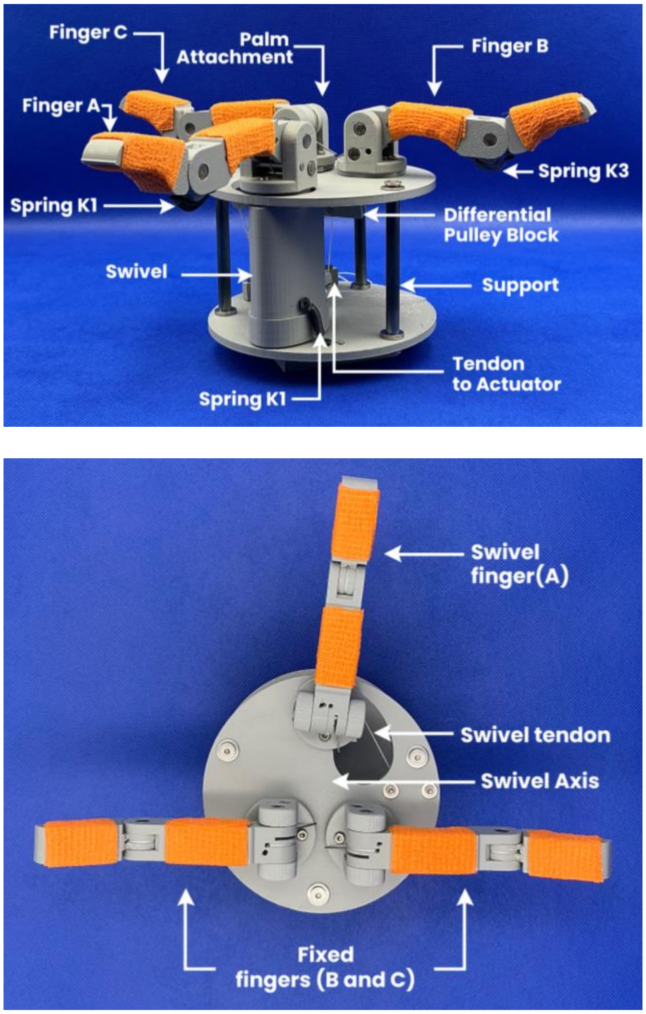

Figure 2. *PhaseHand* (a) side vide and (b) top view.

Here, we introduce *PhaseHand*, a novel single-input underactuated three-fingered robotic hand with an embedded mechanism that sequentially transitions between grasp types in a fully passive manner (Fig. 1). This design enables a more intuitive grasping strategy, eliminating the need for complex sensing, control, or explicit selection of grasp modes. Section II details the mechanical design of the hand and its key components, including a finger swivel mechanism that repositions one of the fingers on the palm, differential pulleys for power transmission, tendon routing, and the careful selection of joint stiffnesses and frictions that facilitate grasp type transitions. Section III demonstrates the hand's functionality across various object grasping scenarios. Finally, in Section IV, we conclude our developments and outline directions for future work.

2. HAND AND MECHANISM DESIGN

In this section, we present the design of *PhaseHand*, an underactuated hand with seven joints (two per finger and a swivel) and a single input (Fig. 2). The digits and hand base were developed using open-source robotic hand CAD files [24]. In addition to off-the-shelf components, the hand included parts—the digits, palm, swivel mechanism, and pulley blocks—that were designed in SolidWorks 2024 and 3D-printed using a

Bambu Lab P1S with PLA filament, ensuring a low-cost fabrication process. To enhance structural stability, three round standoffs were incorporated to support the palm. The resultant hand weighs 330g with a maximum aperture (inter-digit distance) of 170 mm, approximately that of a large human hand. Self-adherent cohesive kinesiology bandages (OK TAPE, El Monte, CA) were used to wrap the distal and proximal links of all three fingers in the hand to increase friction and reduce slip when grasping the target objects; bandages are made of non-woven fabric and hypoallergenic glue.

2.1 Grasp Phase Inspiration

The transition from power to tripod to pinch grasp in *PhaseHand* was partly inspired by observations of the Osprey (Pandion haliaetus) foot. While not unique to Ospreys, these birds possess the ability to reverse their fourth toe, transitioning from an anisodactyl configuration (three toes forward, one backward) to a zygodactyl arrangement (two toes forward, two backward) [25]. Notably, the zygodactyl configuration has been observed more frequently during fishing [26], but qualitative observations suggest that the foot initially begins in a closed anisodactyl position. As the Osprey approaches its prey, the foot extends and transitions to an open anisodactyl configuration before splaying its fourth toe to form a zygodactyl configuration. Within a single stroke, the Osprey effectively sequences two distinct functional grasp types. We draw inspiration from this natural strategy to implement a similar sequential grasp transition in robotics. Here we develop a proof-of-concept design with a simpler morphology that only includes 3 digits while preserving the swiveling mechanism. Anatomically, while some splaying occurs in all digits, Osprey's primary swivel occurs in only one, therefore it was sufficient to exclude one of the remaining digits in the robot hand design.

Distinct grasp types in robotic and prosthetic hands are typically designed to meet specific object grasping requirements—for example, power grasps for larger objects that require greater finger wrapping and precision grasps, such as tripod and pinch, for smaller, lighter objects [27]. The sequential transition between the three selected grasp types in *PhaseHand* is inspired by the natural progression observed in the human hand—from power (five-digit contact) to tripod (three-digit contact) to pinch (two-digit contact)—where the number of digits decrease as grasp precision requirements increase. Being unconstrained by anthropomorphic hand design, *PhaseHand* represents the power grasp with a fully splayed three-digit configuration, where all digits face the center of the palm.

2.2 Grasp Configurations

To maintain mechanical simplicity, two of the three fingers are fixed in a directly opposing configuration, as they would be in a pinch grasp, while the third finger is mounted on a swivel. This design results in a non-rotationally symmetric, yet spherical, power grasp, and a tripod grasp, a cylindrical grasp where two of the digits remain parallel with only one opposing the third (Fig. 1). We refer to the swiveling digit as finger A, which primarily determines the grasp type. The digit toward which finger A swivels is finger B, while the single opposing digit in the tripod grasp is finger C. These correspond to the middle finger, index finger, and thumb in an anthropomorphic hand, respectively.

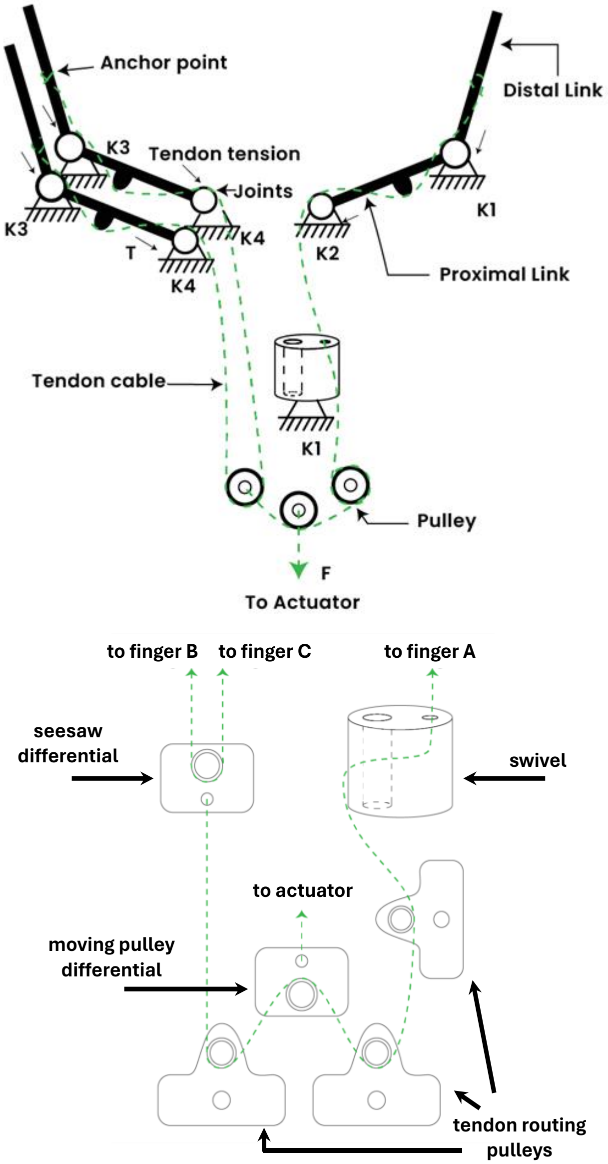

Figure 3. (a) Actuation schematic of the entire hand detailing locations of the springs. (b) A simplified schematic of the force routing in the base of the hand.

The grasp transition sequence can be clearly observed when the hand is actuated without object interaction (Fig. 1). First, finger A swivels 90 degrees toward finger B, aligning in a parallel configuration to form a 2 vs. 1 tripod configuration. Once the swivel reaches a hard stop, finger A begins closing. Only after finger A fully closes—resulting in a pinch grasp—do fingers B and C initiate their synchronized closing sequence. This staged motion is achieved through careful selection of joint stiffnesses and static frictions. Specifically, the stiffness and friction are

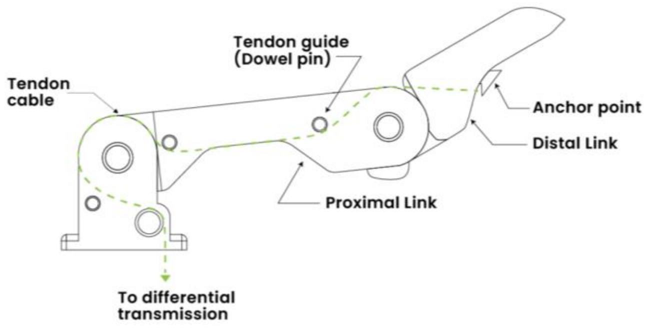

Figure 4. Finger and tendon routing schematic. Each finger's joints are coupled using a single tendon.

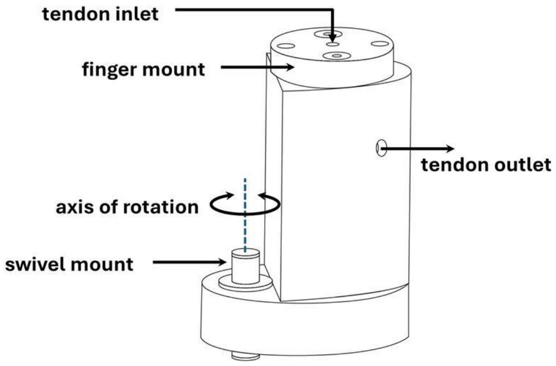

Figure 5. Schematic of the swivel mechanism. The tendon is routed from the top of the swivel coming from the finger and out the side of the swivel to apply a horizontal force.

lowest in the swivel mechanism, followed by the proximal joint of finger A, then the distal joint of finger A, and finally the proximal and distal joints of fingers B and C. Friction is present at all joints, but the lower spring stiffness in the swivel mechanism causes it to be the first to rotate under increasing cable tension. The hard stop in the swivel, and likewise in finger A closure, is designed such that overcoming subsequent joint stiffnesses and frictions requires greater force, ensuring a predictable transition sequence. Due to the underactuated mechanism, it is difficult to precisely predict forces at the fingertips. However, at the fully open configuration, we expect a nominal force output of 0.5*F at digit A and 0.25*F at digits B and C, where F is the applied cable tension. This force distribution will be redistributed by the differential mechanism as the digits encounter resistance.

2.3 Hand Components

All joints in the *PhaseHand* are rigid to ensure high torsional stiffness, enhancing robustness during motion. In the finger design, the distal joints are coupled using spring of higher stiffnesses than the proximal joint, keeping the grasping surface concave and contact forces low [15]. The spring stiffnesses were heuristically selected to achieve the finger closing sequence proposed by this work. Each link is paired with different restorative springs (Fig. 2):

- K1 = 0.40 lbs/in is the stiffness of the extension springs used at the distal joint of finger A and the swivel mechanism.
- K2 = 0.18 lbs/in is the stiffness of the torsion spring used at the proximal joint of finger A.
- K3 = 0.84 lbs/in is the is the stiffness of the extension springs used at the distal joints of finger B and finger C.
- K4 = 0.28 lbs/in is the stiffness of the torsion springs used at the proximal joints of finger B and finger C.

Extension springs are used at the joint between the distal and proximal links, while torsion springs are used at the joint between the proximal link and the palm attachment. As mentioned in the previous section, fingers B and C are coupled with identical spring stiffnesses, ensuring they nominally close at the same speed and time during actuation. The stiffness ratio of the distal joints (finger A to fingers B and C) is 0.476, while the proximal joint stiffness ratio is 0.625. The distal and proximal links of each finger measure 57 mm and 79 mm, respectively. The hand base is 88 mm tall with 114 mm diameter. The tendon (Power Pro Spectra 100 lb. fishing line) was selected for its high tensile strength [17].

2.4 Underactuation and Power Transmission

While differential transmission can be achieved in several ways [12], we leverage moveable pulleys and the seesaw mechanism (also known as the whiffle-tree differential) in our design (Fig. 3), both with a diameter of 3/8 inch. As in other underactuated hands, if any joint of the *PhaseHand*—including the swivel—encounters resistance due to object constraints or friction at the finger pads, the actuation force is passively distributed to the remaining joints. This allows the fingers and swivel to conform to the object's surface, potentially resulting in intermediate grasp configurations beyond the three primary types highlighted here (Fig. 4). Notably, in the current design, a power grasp may exert some shear force during a grasp on the object's surface as finger A attempts to rotate into the tripod configuration. When a tripod or pinch grasp is desired in advance, the hand can simply be pre-actuated to the appropriate configuration by pre-tensioning of the cable. In that case, digit A would be curled towards the palm and away from workspace, avoiding interfering with the grasp.

2.5 Tendon Routing

Finger A and the swivel mechanism are actuated by a single tendon. The swivel mechanism is housed within the palm based and is attached to finger A through a U-shaped slot that provides finger clearance during swivel movement. The tendon guided directly into the palm from finger A is rerouted in a 90° angle through swivel to apply a torque around the swivel's axis of rotation (Fig. 5). Tendons from fingers B and C are routed through a pulley-based differential that distributes the force equally among them. The differential connected to fingers B and C directly is connected to another differential that distributes the

Figure 6. Grasping different objects using the *PhaseHand*. Left to right: fully open hand configuration, Pringles can is grasped using pinch grasp, Pringles can is grasped using tripod (cylindrical) grasp, soft ball, towel, and marker.

Table 1. Objects grasped using *PhaseHand*

Object	Weight (g)	Shape
Pringles can	195	Cylindrical
Towel	115	Soft/Complaint
Whiteboard marker	15	Cylindrical
Soft ball	110	Spherical

input tension between it and the tendon coming from the swivel (Fig. 3).

3. GRASP CONFIGURATION DEMONSTRATIONS

To evaluate the grasping performance of our robotic hand, we conducted grasping tests using four objects with distinct geometries, each requiring one of the three targeted grasp types. Table 1 details the weight, dimensions, and final hand configuration for each object. In all trials, the hand started in a fully open position directly above the target objects and was moved approximately toward the object's center of mass until contact with the palm was established. The hand was then manually actuated until the fingers wrapped around the object, securing the grasp, after which the object was lifted approximately two feet off the table. During the closing phase, the fingers moved in proportion to their stiffness, continuing until all digits either made contact with the object or reached their kinematic limits. Due to the hand's differential transmission, if a joint could no longer rotate upon contact with an object, the remaining actuation force was redistributed to other joints until the actuation limit was reached. Fig. 6 illustrates both the initial hand posture and the final grasp configurations after lifting the objects. The robotic hand successfully performed power, tripod, and pinch grasps on the selected objects. However, grasping attempts without adhesive bandages resulted in minimal success, highlighting the critical role of friction in achieving stable grasps [28,29]. A grasp was considered successful when the target object is firmly grasped, lifted to a height of two feet above the table and no slip was recorded for an average time of 3 – 5 seconds. 2 – 3 trials were performed for each object and successful grasps were recorded for all the objects used. Grasping off-center, such as at the end of a marker or a Pringles can, introduced torque during lifting, causing the object to rotate within the fingers. Despite this rotation, the objects remained securely grasped as they were lifted off the table. Table 2 provides an overview of some research and commercial robotic hands and shows how our hand compares to them on certain criteria. In terms of weight and achieving underactuation in robotic hands, the hand compares favorably with other similar research and commercially available robotic hands.

4. CONCLUSION

This paper presented the design and implementation of *PhaseHand*, a novel underactuated robotic hand that achieves three distinct grasp types—power, tripod, and pinch—through a sequential grasp transition. By leveraging a tendon-driven differential system, a swiveling digit, and carefully selected joint stiffnesses, *PhaseHand* enables adaptive and compliant grasping while maintaining mechanical simplicity. The ordered grasp transition mimics intuitive human grasping strategies, allowing the hand to conform to a wide range of object geometries.

4.1 Future Work

Despite the proof-of-concept demonstration of *PhaseHand*, several improvements, iterations, and validations are planned.

In the present design, cable tension was manually actuated to allow for safe and secure grasps. In the next iteration we will be implementing a servo motor to fully automate the end-effector, and whose torque will indeed need to be precisely modulated to prevent excessive forces at the fingertips. We will also set up tests to measure the grip force of the hand and the maximum weight it can carry. It will also include design improvements accounting for the modelled joint stiffnesses in the *PhaseHand*.

First, we aim to conduct a comprehensive series of grasping and manipulation tests to quantify the effects of sequential grasp

Table 2. Grasper comparison

Hand	# Fingers	# Actuators	Base Height (mm)	Base Width (mm)	Weight (g)	Grip Force (N)
Barrett Hand [30]	3	4	75.5	130	1200	15
Grab lab Open-source design [24]	4	1	75 - 90	100	400	10
2G Velo [31]	2	1	80	45		10 - 20
Robotiq (2-finger)	2	1	90	140	890	30 - 100
Robotiq (3-finger)	3	2	126	126	2300	15 - 60
Meka H2	4	5	63	96	800	
Schunk SDH Hand [32]	3	7	98	122	1950	
The Hydra Hand [20]	4	2		60		
Hybrid gripper [33]	2	12		100	200	
SLUM hand [34]	3	2	300	130	3500	
Phasehand	3	1	88	114	330	

transitions on actuation requirements and compare *PhaseHand*'s grasping performance to other hands that support variable grasp types. One observed limitation is that without sufficient object engagement or adequate friction between the object and digits, the hand may prematurely transition away from a power grasp, potentially leading to improper object caging and failed grasps [35]. To address this, future iterations will explore mechanisms that reliably jam the swiveling digit upon object contact, ensuring that a power grasp can be maintained when needed. Additionally, given the importance of grasp transitions in prosthetic applications, we plan to develop an anthropomorphic version of *PhaseHand*. Since voluntary-opening end-effectors can be preferred in prosthetic applications to reduce user fatigue [36], a future version could be designed to operate in reverse—starting with a closed pinch grasp and sequentially transitioning to a tripod and then a power grasp. Finally, alternative grasp transition sequences will be explored to expand the hand’s grasping and manipulation capabilities across a broader range of tasks.

REFERENCES

[1] Lee, Jungpyo, Sebastian D. Lee, Tae Myung Huh, and Hannah S. Stuart. "Haptic search with the smart suction cup on adversarial objects." IEEE Transactions on Robotics 40 (2023): 226-239.

[2] Gloumakov, Yuri, Tae Myung Huh, and Hannah S. Stuart. "Fast In-Hand Slip Control on Unfeatured Objects with Programmable Tactile Sensing." *IEEE Robotics and Automation Letters* (2024).

[3] Cutkosky, Mark R. *Robotic grasping and fine manipulation*. Vol. 6. Springer Science & Business Media, 2012.

[4] Feix, Thomas, Javier Romero, Heinz-Bodo Schmiedmayer, Aaron M. Dollar, and Danica Kragic. "The grasp taxonomy of human grasp types." IEEE Transactions on human-machine systems 46, no. 1 (2015): 66-77.

[5] Sharma, Dhruv, Kirti Tokas, Aviral Puri, and Krishna Sharda. "Shadow hand." *Journal of Advance Research in Applied Science ISSN* 2208 (2014): 2352.

[6] Andrychowicz, OpenAI: Marcin, Bowen Baker, Maciek Chociej, Rafal Jozefowicz, Bob McGrew, Jakub Pachocki, Arthur Petron et al. "Learning dexterous in-hand manipulation." The International Journal of Robotics Research 39, no. 1 (2020): 3-20.

[7] Imtiaz, Muhammad Babar, Yuansong Qiao, and Brian Lee. "Prehensile and non-prehensile robotic pick-and-place of objects in clutter using deep reinforcement learning." *Sensors* 23, no. 3 (2023): 1513.

[8] Hughes, Josie, Utku Culha, Fabio Giardina, Fabian Guenther, Andre Rosendo, and Fumiya Iida. "Soft manipulators and grippers: A review." *Frontiers in Robotics and AI* 3 (2016): 69.

[9] Della Santina, Cosimo, Cristina Piazza, Giorgio Grioli, Manuel G. Catalano, and Antonio Bicchi. "Toward dexterous manipulation with augmented adaptive synergies: The pisa/iit softhand 2." *IEEE Transactions on Robotics* 34, no. 5 (2018): 1141-1156.

[10] Birglen, Lionel, Thierry Laliberté, and Clément Gosselin, "Grasp stability of underactuated fingers." *Underactuated robotic hands* (2008): 61-115.

[11] Odhner, Lael U., Leif P. Jentoft, Mark R. Claffee, Nicholas Corson, Yaroslav Tenzer, Raymond R. Ma, Martin Buehler, Robert Kohout, Robert D. Howe, and Aaron M. Dollar. "A compliant, underactuated hand for robust manipulation." *The International Journal of Robotics Research* 33, no. 5 (2014): 736-752.

[12] Birglen, Lionel, and Clement M. Gosselin. "Force analysis of connected differential mechanisms: Application to grasping." *The International Journal of Robotics Research* 25, no. 10 (2006): 1033-1046.

[13] Kanner, OY, and Dollar, AM. "Optimization of Coupling Ratio and Kinematics of an Underactuated Robot Leg for Passive Terrain Adaptability." *Proceedings of the ASME 2012 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Volume 4: 36th Mechanisms and Robotics Conference, Parts A and B.*

Chicago, Illinois, USA. August 12–15, 2012. pp. 1051-1058. ASME.

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

[15] A.M. Dollar and R. D. Howe, "The Highly Adaptive SDM Hand: Design and Performance Evaluation," *International Journal of Robotics Research*, v. 29, n. 5, pp. 585–597, 2010.

[16] Foody, J, Maxwell, K, Hao, G, & Kong, X. "Development of a Low-Cost Underactuated and Self-Adaptive Robotic Hand." *Proceedings of the ASME 2014 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. *Volume 5B: 38th Mechanisms and Robotics Conference*. Buffalo, New York, USA. August 17–20, 2014.

[17] R. R. Ma, L. U. Odhner and A. M. Dollar, "A modular, open-source 3D printed underactuated hand," *2013 IEEE International Conference on Robotics and Automation*, Karlsruhe, Germany, 2013, pp. 2737-2743.

[18] Catalano, Manuel G., Giorgio Grioli, Edoardo Farnioli, Alessandro Serio, Cristina Piazza, and Antonio Bicchi. "Adaptive synergies for the design and control of the Pisa/IIT SoftHand." *The International Journal of Robotics Research* 33, no. 5 (2014): 768-782.

[19] Backus, Spencer B., and Aaron M. Dollar. "An adaptive three-fingered prismatic gripper with passive rotational joints." *IEEE Robotics and Automation Letters* 1, no. 2 (2016): 668-675.

[20] Chappell, Digby, Fernando Bello, Petar Kormushev, and Nicolas Rojas. "The hydra hand: a mode-switching underactuated gripper with precision and power grasping modes." *IEEE Robotics and Automation Letters* 8, no. 11 (2023): 7599-7606.

[21] Scheme, Erik, and Kevin Englehart. "Electromyogram pattern recognition for control of powered upper-limb prostheses: state of the art and challenges for clinical use." *Journal of Rehabilitation Research & Development* 48, no. 6 (2011).

[22] Leddy, Michael T., and Aaron M. Dollar. "The yale myoadapt hand: A highly functional and adaptive single actuator prosthesis." *IEEE Transactions on Medical Robotics and Bionics* 4, no. 3 (2022): 807-820.

[23] Zhang, Wenjuan, Melissa White, Maryam Zahabi, Anna T. Winslow, Fan Zhang, He Huang, and David Kaber. "Cognitive workload in conventional direct control vs. pattern recognition control of an upper-limb prosthesis." In *2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, pp. 2335-2340. IEEE, 2016.

[24] Ma, Raymond, and Aaron Dollar. "Yale openhand project: Optimizing open-source hand designs for ease of fabrication and adoption." *IEEE Robotics & Automation Magazine* 24, no. 1 (2017): 32-40.

[25] Polson, J. R. "Weapons to cradle: birds put the toe to the task." *American Birds* 47 (1993): 216-219.

[26] Sustaita, Diego, Yuri Gloumakov, Leah R. Tsang, and Aaron M. Dollar. "Behavioral correlates of semi-zygodactyly in Ospreys (Pandion haliaetus) based on analysis of internet images." *PeerJ* 7 (2019): e6243.

[27] Cutkosky, Mark R., and Robert D. Howe. "Human grasp choice and robotic grasp analysis." *Dextrous robot hands* (1990): 5-31.

[28] Cutkosky, Mark R., and Paul K. Wright. "Friction, stability and the design of robotic fingers." *The International Journal of Robotics Research* 5, no. 4 (1986): 20-37.

[29] Bicchi, Antonio, J. Kenneth Salisbury, and David L. Brock. "Experimental evaluation of friction characteristics with an articulated robotic hand." In *Experimental Robotics II: The 2nd International Symposium, Toulouse, France, June 25–27 1991*, pp. 153-167. Springer Berlin Heidelberg, 1993.

[30] Townsend, William. "The BarrettHand grasper–programmably flexible part handling and assembly." Industrial Robot: an international journal 27, no. 3 (2000): 181-188.

[31] Ciocarlie, Matei, Fernando Mier Hicks, Robert Holmberg, Jeffrey Hawke, Michael Schlicht, Jeff Gee, Scott Stanford, and Ryan Bahadur. "The Velo gripper: A versatile single-actuator design for enveloping, parallel and fingertip grasps." The International Journal of Robotics Research 33, no. 5 (2014): 753-767.

[32] Ruehl, Steffen W., Christoper Parlitz, Georg Heppner, Andreas Hermann, Arne Roennau, and Ruediger Dillmann. "Experimental evaluation of the schunk 5-finger gripping hand for grasping tasks." In *2014 IEEE International Conference on Robotics and Biomimetics (ROBIO 2014)*, pp. 2465-2470. IEEE, 2014.

[33] Cui Y, An X, Lin Z, Guo Z, Liu X-J, Zhao H. Design and implementation of an underactuated gripper with enhanced shape adaptability and lateral stiffness through semi-active multi-degree-of-freedom endoskeletons. *The International Journal of Robotics Research.* 2024;43(6):873-896.

[34] J. Hsu, E. Yoshida, K. Harada and A. Kheddar, "Self-locking underactuated mechanism for robotic gripper," *2017 IEEE International Conference on Advanced Intelligent Mechatronics (AIM), Munich, Germany*, 2017, pp. 620-627.

[35] Makita, Satoshi, and Weiwei Wan. "A survey of robotic caging and its applications." *Advanced Robotics* 31, no. 19-20 (2017): 1071-1085.

[36] Berning, Kelsey, Sarah Cohick, and Reva Johnson. "Comparison of body-powered voluntary opening and voluntary closing prehensor for activities of daily life." *Journal of rehabilitation research and development* 51, no. 2 (2014): 253.