Preliminary Design of a Thermally Actuated Three-finger Compliant Gripper Based on Topology Optimization

Estefania Hermoza Llanos*, Prof. Dr.- Ing. Mathias Hüsing*, Univ.-Prof. Dr.-Ing. Dr. h. c. Burkhard Corves*, Prof. Anupam Saxena**
* Institute of Mechanism Theory, Machine Dynamic and Robotics, 52062 Aachen, Germany. {hermoza-llanos, huesing, corves}@igmr.rwth-aachen.de
** Indian Institute of Technology Kanpur, 208016, India. anupams@iitk.ac.in

Abstract

The task of grasping has always been important in the daily life of human beings, in medicine, in production lines and even in nature. There has been an interest to replicate or even improve the tasks that human beings can do naturally with their hands, but through new machines and mechanisms. At the same time, compliant mechanisms are a technology that has been developed and is being improved in recent years to design precise, monolithic and functional mechanisms. Therefore, it is appropriate to think about the design of a gripper based on flexible mechanisms, which allows us to grasp objects with different shapes in different ways.

We design a spatial, compliant gripper (**Figure 1**.a), considering the best arrangement, number of units, degrees of freedom, flexibility in terms of the types of objects that can be grasped and manipulated, and ease in fabrication according to previous researches [1, 2, 3, 4]. We reckon that a symmetrically positioned three finger unit gripper makes the design versatile, allowing for objects with different geometries to be grasped, as a three finger gripper closes toward the central axis of the object [3, 5]. The 3-finger configuration is chosen because it is intended to design a gripper that has the ability to not only perform assembly, pick and place and simple manipulation tasks, but also to have more accuracy and precision in its work [4]. This statement is also validated through the experiments conducted by Hershkovitz, M. *et al* [6], in which three quality measures were analyzed for a two and a three-finger gripper grasping a planar trapezoidal object:

- Energy-like grasping quality: Effort made when performing force closures.
- Minmax grasping quality: Minimum force required to obtain a good firm grip.
- Entropy grasping quality: Uniformity of the distribution of gripping forces.

In this study the three-finger gripper demonstrated a higher quality of grip on two of the three measurements mentioned above.

As for the configuration of the gripper fingers, the units are positioned symmetrically and each unit is a replica of the other (Figure 1.a). Each unit is capable of achieving contact at several points with some circular or prismatic object in its corresponding deformation plane, so that the spatial gripper is capable of gripping objects with curved or prismatic surfaces. To eliminate/minimize parasitic motion (perpendicular to the plane of deformation), each unit is a paired setup of two flexible, monolithic optimized fingers, connected in the perpendicular direction to the cross section via rigid, cylindrical rods. It should be noted that a three-finger gripper is efficient if the configuration of its fingers can be modified, so that it can adapt to the shape of the objects to be gripped; therefore a compliant base was designed, which allows the rotation of each finger unit about an axis perpendicular to the base that pass through the center of the whole gripper (**Figure 2**), this compliant base allows the independent rotation of each unit finger due to the large deflection of a cantilever beam.

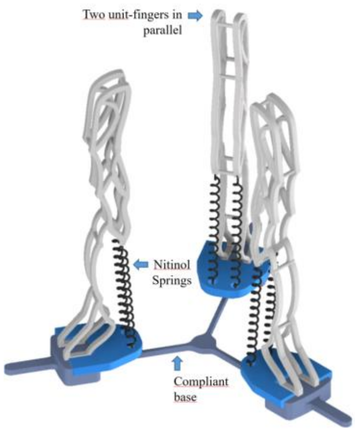

Figure 1.a - Three-finger Compliant Gripper parts

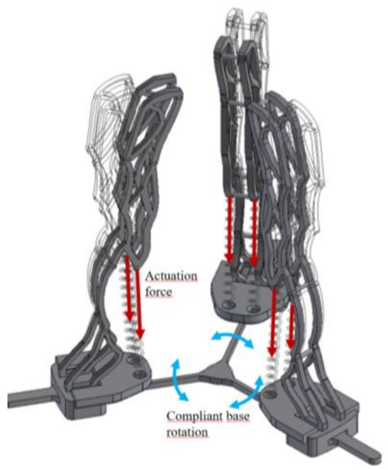

Figure 1.b - Three-finger Compliant Gripper actuated

DOI: 10.17185/duepublico/77385

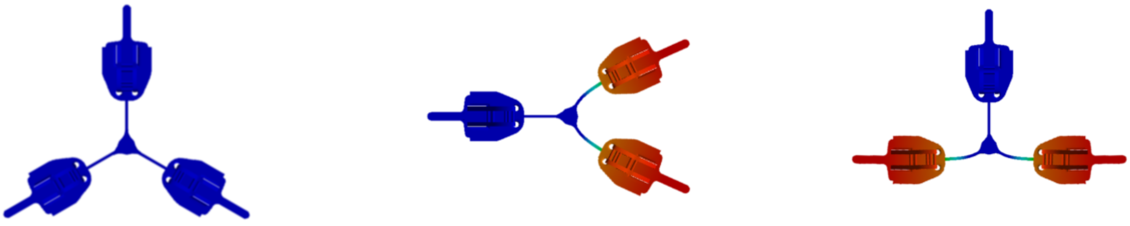

Figure 2 – Configurations of the gripper

The independent actuation of each finger is accomplished via a Nitinol spring configuration. This special metal is a non-magnetic alloy composed of titanium and nickel. It has the ability to return to its original shape, after being deformed, by being heated up [7]. The idea is that the spring configuration is deformed when the system is "at rest position". As soon as the system needs to deform to achieve contact with the object, the springs will be heated through joule heating and contract, exerting the necessary force for the fingers gripper to deform. The activation temperature of Nitinol springs has a range of 30°C up to 130°C, depending on the exact chemical composition of the metal used. This must be taken into account when designing and heating them, as they will be in contact with the fingers, which, being made of PLA, have a glass transition temperature between 50°C and 80°C [8]. The controlled actuation of each finger allows for control of the force required for the contact points between the finger and the object to be gripped, since the force requirements may vary according to the object. The actuation through Nitinol springs is one candidate mode that allows the system to be monolithic and to explore the option of including shape memory alloys (SMA) into the design of compliant mechanism. Nevertheless, it is important to consider that there could be other actuations methods that need to be explored and compared.

The design of each single compliant finger is accomplished via a significantly revised topology optimization process compared to our previous endeavor [9]. The algorithm designs a compliant finger based on topology optimization method through Hill Climber stochastic search. Each candidate design can have initial curvature in each beam and the coordinates of its nodes are posed as design variables in a way that overlapping members can be ideally avoided. Considering various actuation possibilities, one with guided force is incorporated. For instance, when an actuating tether is pulled over a roller/pulley, the input force points to a prescribed/stationary point, and its direction depends on the deformation of the finger. We also consider penalizing and thus eliminating candidate designs in which at least one of their beams has stress higher than the maximum allowed, which is calculated via the yield stress and a user-defined safety factor. To render the flexible finger capability of grasping objects of various shapes, we facilitate the study of contact with two surfaces: one circular and the other flat (**Figure 3**.a. and Figure 3.b.). The algorithm tests each candidate design and submits it to contact with each surface separately, considering the number of contact points and magnitudes of the contact forces as the outcomes for the optimization to be maximized. This new finger design (Figure 3.c.) can have multiple points of contact with the object to be gripped. The mechanical advantage, which is the ratio between the contact forces and the input force is increased. The possibility of varying end slopes have helped render different curvatures to members of the finger so that the latter is versatile and can have a good contact with both flat and curved objects (or objects with finite curvature). Furthermore, stress concentration is reduced, due the fact that there are no abrupt changes in the connection of beams.

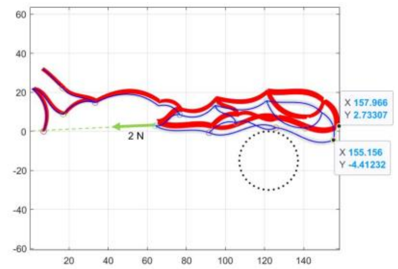

Figure 3.a.- Contact with a circular surface of a unit finger based on topology optimization

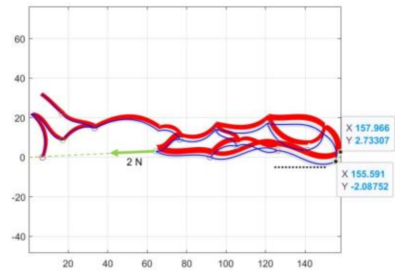

Figure 3.b.- Contact with a flat surface of a unit finger based on topology optimization

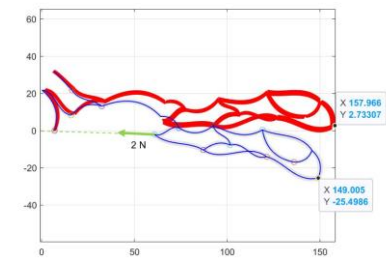

Figure 3.c.- Deformation of a unit finger based on topology optimization

To conclude, this work provides a new design process for a three-finger gripper in two aspects: design and optimization of the topology of a monolithic finger by analyzing large and contact deformations with user-defined surfaces, as well as feature of the compliant mechanism on the base that allows to change the configuration of the fingers of the gripper.

References

[1] R. BALASUBRAMANIAN and V. SANTOS, in *The Human Hand as an Inspiration for Robot Hand Development*, Springer, 2014, pp. 219-246.

[2] I. STARETU and S. JITARU, "Reconfigurable Anthropomorphic Gripper with Three Fingers: Synthesis, Analysis, and Simulation," *Applied Mechanics and Materials,* 2015.

[3] J. SHINTAKE, V. CACUCCIOLO, D. FLOREANO and H. SHEA, "Soft Robotic Grippers," *ADVANCED MATERIALS,* p. 33, 24 May 2018.

[4] Z. SAMADIKHOSHKHO, K. ZAREINIA and F. JANABI-SHARIFI, "A Brief Review on Robotic Grippers Classifications," *IEEE Canadian Conference of Electrical and Computer Engineering (CCECE),* 2019.

[5] T. BELYTSCHKO and B. HSIEH, in *Non-Linear Transient Finite Element Analysis with Convected Coordinates*, 1973, pp. 255-271.

[6] M. HERSHKOVITZ, U. TASCH and M. TEBOULLE, "Toward a Formulation of the Human Grasping Quality Sense," *Journal of Robotic Systems 12(4),* pp. 249-256, 1994.

[7] C. ZANOTTI, A. GIULIANI, A. TUISSI, S. ARNABOLDI and R. CASATI, "Response of NiTi SMA wire electrically heated," in *European Symposium on Martensitic Transformations (ESOMAT)*, Prague, Czech Republic, 2009.

[8] C. P. S.N. Vouyiouka, "Mechanistic Aspects of Solid-State Polycondensation," in *Polymer Science: A Comprehensive Reference*, Elsevier B.V., 2012, pp. 857-874.

[9] E. HERMOZA, M. HUESING, B. CORVES and A. SAXENA, "Compliant Finger gripper based on topology optimization," in *Microactuators, Microsensors and Micromechanisms (MAMM 2022)*, Hyderabad, India, 2022.

[10] M. CRISFIELD, Nonlinear Finite Element Analysis of Solids and Structures, New York: John Wiley and Sons Inc., 1991.

[11] Z. HONGYING, S. KUMAR, F. CHEN, J. Y. H. FUH and M. YU WANG, "Topology Optimized Multimaterial Soft Fingers for Applications on Gripper, Rehabilitation, and Artificial Hands," in *IEEE/ASME TRANSACTIONS ON MECHATRONICS 2019*, 2019.

[12] L. HOWELL, S. MAGLEBY and B. OLSEN, Handbook of Compliant Mechanisms, United Kingdom: WILEY, 2013.

[13] C. LIU, Y. CHEN and S. YANG, "Topology Optimization and Prototype of a Multimaterial-Like Compliant Finger by varying the Infill Density in 3D Printing," in *Mary Ann Liebert, Inc*, Taiwan, 2021.

[14] T. BELYTSCHKO and L. GLAUM, in *Applications of Higher Order Corotational Stretch Theories to Nonlinear Finite Element Analysis*, 1979, pp. 175-182.

[15] Z. CHEN, H. RAHIMI NOHOOJI and C. CHEW , "Development of Topology Optimized Bending-twisting Sof Finger," in *Journal of Mechanisms and Robotics*, Singapore, 2022.

[16] D. PETKOVIC and N. PAVLOVIC, "Compliant Multi-Fingered Adaptative Robotic Gripper," in *Kolloquium Getriebetechnik - Ilmenau 2013*, Ilmenau, Germany, 2013.

[17] D. LAVAYEN-FARFAN, M. BOADA and J. RODRIGUEZ-HERNANDEZ, "Bending collapse analysis for thin and medium-thin-walled square and rectangular hollow shapes," in *Thin-Walled Structures*, 2021.

DOI: 10.17185/duepublico/77385
URN: urn:nbn:de:hbz:465-20230314-140604-3