THESIS

DESIGN AND CHARACTERIZATION OF VACUUM ACTUATED SOFT ROBOTIC GRIPPER

NOER FADZRI PERDANA DINATA
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PROGRAM STUDI MAGISTER TEKNIK MESIN
FAKULTAS TEKNIK
UNIVERSITAS SRIWIJAYA
2021

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Submitted as one of the requirements for obtaining a Master's Degree in Mechanical Engineering at the Universitas Sriwijaya Faculty of Engineering

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Palembang, June 2021

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PREFACE

Praise be to Allah's blessing, for the opportunity to finish the thesis proposal titled, **Design and Characterization of Vacuum Actuated Soft Robotic Gripper.** This proposal has been prepared as one of the requirements to acquire Master's Degree of Mechanical Engineering of Universitas Sriwijaya. Author acknowledged the completion of this proposal has been influenced and inspired by support and direction from many parties.

Besides the administration reason, the objective of this proposal is to introduce the design of soft robotic gripper. Along with the notion to introduce technological advance in robotic field to be able to operate in fragile environment. The idea of human-machine interaction especially in an era of Industry 4.0 is unavoidable. Hopefully, this research as a whole could be beneficiary for human kind and technology integrated system in the future.

Palembang, June 2021

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STATEMENT AGREEMENT FOR PUBLICATION

The author, namely as stated below:

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Herewith agreed to give permit to Supervisors and Universitas Sriwijaya to publish this research report for academic purpose. The agreement applied as if the author failed to publish any academic paper within 1 (one) year after the approval. In the case of publication, author has agreed to put supervisors as the corresponding author.

This statement was sincerely made of author's own free will.

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ABSTRACT

DESIGN AND CHARACTERIZATION OF VACUUM ACTUATED SOFT ROBOTIC GRIPPER
Scientific Paper in the form of Thesis, 8 June 2021

Noer Fadzri Perdana Dinata; supervised by Agung Mataram and Muhammad Abu Bakar Sidik

Perancangan dan Pengkarakterisasian Tangan Robot Penggenggam dengan Metode Aktuasi Tekanan Vakum

xii + 40 pages, 2 table, 18 figures

Grasping of fragile objects is a currently active area of research which is advancing continuously throughout the years. Although conventional robotic gripper systems have proved their versatility, a recent favourable option is to utilized soft robotic grippers to hold various shapes and interacting with unstructured environments. The principal concept of soft grippers is to handle or manipulate various fragile items without harming the object. In this research, we show structured soft-vacuum actuators covered with commercially available latex balloons as a membrane. These actuators are directly manufactured into segmented soft robotic fingers using commercially affordable fused deposition modelling 3D printer. Due to its flexible structural deformation, the task could be achieved without additional complications like their rigid-bodied counterparts. Some advantages of this development are its economical production cost, vastly available material, straight-forward fabrication, and large payload to weight ratio. While the gripper only weighs approximately 63 grams, it capable of lifting to 800 grams load. These actuators' behaviour is predicted using numerical analysis in finite element modelling, which then verified through experiments. On average, the soft fingers need only -70 kPa to perform the task and fulfil full motion. Furthermore, several structural configurations have been investigated in order to observe any relation between the geometry to the actuator performance. The research presented here confirms that a slight modification of geometry could reduce the deviation after repetitive actuation of soft vacuum actuator up to 50%. The findings presented in this study add to the understanding of geometry, force distribution, and its relation to performance deviation of soft actuators. Finally, the soft structures are fabricated into a soft robotic gripper. Such gripper is utilized to pick up several items, to demonstrate its application to grasp objects.

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CHAPTER 1
INTRODUCTION

1.1 Background

The grasping of delicate objects is an ongoing field of inquiry that increasingly progresses through the years. Although the versatility of traditional robotic gripper systems has been shown, a recent favorite alternative is to use soft robotic grippers that can grasp diverse shapes and interact with unstructured environments. The key idea is that many delicate objects can be handled or manipulated without damaging the object.

The role of manipulating delicate objects is accomplished in soft robotics by substituting the principle of articulated finger joint motion for deformation of the material. The idea is to shape the soft gripper around the target as it comes to touch. The task could be done without further problems such as rigid-robot equivalents due to their versatile structural deformation.

1.2 Problem Statement

Excessive use of positive pneumatic pressure is now repeatedly recorded as the actuation method for soft robotic inventions (Ilievski *et al.*, 2011; Hughes *et al.*, 2016; Miriyev, Stack and Lipson, 2017; Vasios *et al.*, 2019). Recent innovations however revealed interest in a soft robot actuated by vacuum pressure (Brown *et al.*, 2010; Robertson and Paik, 2017), given its implicit fail-safe operation (Yang *et al.*, 2016). The latter actuation term is then being praised for its repeatability and performance under repetitive actuation.

There are also similarities between the soft robotic systems that actuate on positive or negative pressure. The actuation concept of soft pneumatic actuators is basically equal, whether they are provided by a compressor or by a vacuum pump where both required internal pressure to actuate. For example, an excellent vacuum-actuated gripper is called universal gripper (Brown *et al.*, 2010) where the principle of granular jamming is implemented in conjunction with the object's form. A recent progress also uses a 3D printing system (Tawk, Spinks and Alici, 2019) to incorporate a simple fabrication, with the benefits of quick prototyping and various potential applications.

Much of the academic literature of soft pneumatic actuator (SPA) pays particular attention to positive pressurized air actuation (Ilievski *et al.*, 2011; Hughes *et al.*, 2016; Miriyev, Stack and Lipson, 2017; Vasios *et al.*, 2019). It was used in numerous applications, in particular for the production of soft robotic grippers. Not until recently, a potential 'fail-safe operation' for a vacuum actuated continuum robot was claimed by (Robertson and Paik, 2017). This study explores the use of negative pressure as the actuation method in a new perspective on robotic soft fingers.

1.3 Research Scope and Objective

For this research, an extensively available latex balloons was used to cover the soft-vacuum actuators 3D printed structure. A commercial fused deposition modelling (FDM) 3D printer was used to fabricate the actuator into segmented soft robotic finger. The fabricated soft robotic finger was considered as a sample to be characterized. This study measured the actuation / deactuation response, along with energy consumption for actuation, as a performance related characterization. In addition, the trajectory of the finger motion was analyzed using finite element analysis software, which further verified experimentally. As a demonstration in applied field, a three-finger gripper configuration was developed and tested to grasp and picked several types of objects.

1.4 Research Limitation

This study limits its interest on soft robotic system for gripping fragile objects application. To further put clear boundary in this research, the fragile objects is determined as brittle items that under certain stress will cause the items to fracture with elastic deformation and without significant plastic deformation. The fragile objects under consideration is presented in chapter 2, sub-chapter 2.4. Force value that imply to object fractures is set as maximum value of force that allowed to be generated on the soft robotic finger. Therefore the design considered the force value to be less than the sample fragile objects can endures.

By taking the above limitation, any potential benefit for the development such as locomotion and object manipulation will be neglected. Subsequently, the material used in this study will focused solely on 3D printed Thermoplastic polyurethane (TPU) material as prototype sample, any possible used of other materials will not be considered.

1.5 Research Advantage

The benefits of this development are the economic cost of fabrication, the vastly usable material, straight-forward manufacturing, and high weight to payload ratio. The demonstration shows that the soft robotic gripper capable of lifting up to 800 *grams* of load, while only weighs around 63 *grams*. The behavior of these actuators is modeled by numerical analysis in finite element modeling, and is then confirmed by experiments. On average, soft fingers require only -60 *kPa* to perform the task and perform full motion.

REFERENCES

Avanzini, A. and Gallina, D. (2011) 'Effect of cyclic strain on the mechanical behavior of a thermoplastic polyurethane', *Journal of Engineering Materials and Technology, Transactions of the ASME*, 133(2), pp. 1–9. doi: 10.1115/1.4003101.

Batchu, S. (2014) *Generic MMPDS Mechanical Properties Table*.

Beardmore, P. and Rabinowitz, S. (1974) 'Cyclic Deformation and Fracture in Polymers.', *Appl Polym Symp*, 9(2), pp. 25–29.

Bosman, J. *et al.* (2015) 'Domain decomposition approach for FEM quasistatic modeling and control of Continuum Robots with rigid vertebras', in *IEEE International Conference on Robotics and Automation*, pp. 4373–4378. doi: https://dx.doi.org/10.1109/ICRA.2015.7139803.

Brown, E. *et al.* (2010) 'Universal robotic gripper based on the jamming of granular material', *Proceedings of the National Academy of Sciences of the United States of America*, 107(44), pp. 18809–18814. doi: 10.1073/pnas.1003250107.

Caldwell, D., Tsagarakis, N. and Medrano-Cerda, G. (2000) 'Bio-mimetic actuators: Polymeric Pseudo Muscular Actuators and pneumatic Muscle Actuators for biological emulation', *Mechatronics*, 10(4), pp. 499–530. doi: https://dx.doi.org/10.1016/S0957-4158(99)00071-9.

Chou, C. and Hannaford, B. (1996) 'Measurement and modeling of McKibben pneumatic artificial muscles', *IEEE Transactions on Robotics and Automation*, 12(1), pp. 90–102. doi: https://dx.doi.org/10.1109/70.481753.

Deimel, R. and Brock, O. (2015) 'A Novel Type of Compliant and Underactuated Robotic Hand for Dexterous Grasping', in *Robotics: Science and Systems Foundation*.

Drotman, D. *et al.* (2019) 'Application-driven design of soft, 3-d printed, pneumatic actuators with bellows', *IEEE/ASME Transactions on Mechatronics*, 24(1), pp. 78–87. doi: 10.1109/TMECH.2018.2879299.

Fang, G. *et al.* (2018) 'Geometry-based direct simulation for multi-material soft robots', in *IEEE International Conference on Robotics and Automation*, pp. 4194–4199. doi: https://dx.doi.org/10.1109/ICRA.2018.8461088.

Holzweber, J. and Major, Z. (2014) 'Characterization of the fatigue behavior of tpu's', *13th IMEKO TC15 Youth Symposium on Experimental Solid Mechanics 2014*, pp. 44–47.

Hughes, J. *et al.* (2016) 'Soft Manipulators and Grippers: A Review', *Frontiers Robotics AI. Frontiers Media S.A.*, 3(November), pp. 1–12. doi: 10.3389/frobt.2016.00069.

Ilievski, F. *et al.* (2011) 'Soft Robotics for Chemists', *Angewandte Chemie - International Edition*, 50(8), pp. 1890–1895. doi: 10.1002/anie.201006464.

Kang, R. *et al.* (2013) 'Design, modeling and control of a pneumatically actuated manipulator inspired by biological continuum structures', *Bioinspiration and Biomimetics*, 8(3). doi: https://dx.doi.org/10.1088/1748-3182/8/3/036008.

Krzypow, D. J. and Rimnac, C. M. (2000) 'Cyclic steady state stress-strain behavior of UHMW polyethylene', *Biomaterials*, 21(20), pp. 2081–2087. doi: 10.1016/S0142-9612(00)00138-1.

Liu, X. *et al.* (2015) 'Improving hopping stability of a biped by muscular stretch reflex', in *IEEE-RAS International Conference on Humanoid Robots*, pp. 658–663. doi: https://dx.doi.org/10.1109/HUMANOIDS.2014.7041433.

Marchese, A., Katzschmann, R. and Rus, D. (2015) 'A recipe for soft fluidic elastomer robots', *Soft Robotics*, 2(1), pp. 7–25. doi: https://dx.doi.org/10.1089/soro.2014.0022.

Marchese, A., Onal, C. and Rus, D. (2011) 'Soft robot actuators using energy-efficient valves controlled by electropermanent magnets', in *IEEE Intrenational Conference on Intelligent Robots and Systems*, pp. 756–761. doi: https://dx.doi.org/10.1109/IROS.2011.6048794.

Martinez, R. V *et al.* (2013) 'Robotic Tentacles with Three-Dimensional Mobility Based on Flexible Elastomers', *Advanced Materials*, 25(2), pp. 205–212. doi: 10.1002/adma.201203002.

Miriyev, A., Stack, K. and Lipson, H. (2017) ‘Soft material for soft actuators’, *Nature Communications*, 8(1), pp. 1–8. doi: 10.1038/s41467-017-00685-3.

Morin, S. *et al.* (2012) ‘Camouflage and display for soft machines’, *Science*, 337(6096), pp. 828–832. doi: https://dx.doi.org/10.1126/science.1222149.

Mosadegh, B. *et al.* (2014) ‘Pneumatic networks for soft robotics that actuate rapidly’, *Advanced Funtional Materials*, 24(15), pp. 2163–2170. doi: https://dx.doi.org/10.1002/adfm.201303288.

Omar, M. K., Atkins, A. G. and Lancaster, J. K. (1986) ‘The role of crack resistance parameters in polymer wear’, *Journal of Physics D: Applied Physics*, 19(2), pp. 177–195. doi: 10.1088/0022-3727/19/2/007.

Polygerinos, P. *et al.* (2013) ‘Towards a soft pneumatic glove for hand rehabilitation’, in *IEEE International Conference on Intelligent Robots and Systems*. IEEE, pp. 1512–1517. doi: 10.1109/IROS.2013.6696549.

Pritts, M. and Rahn, C. (2004) ‘Design of an artificial muscle continuum robot’, in *IEEE International Conference on Robotics and Automation*, pp. 4742–4746. doi: https://dx.doi.org/10.1109/ROBOT.2004.1302467.

Qi, H. J. and Boyce, M. C. (2005) ‘Stress-strain behavior of thermoplastic polyurethanes’, *Mechanics of Materials*, 37(8), pp. 817–839. doi: 10.1016/j.mechmat.2004.08.001.

Reynolds, D. *et al.* (2003) ‘Modelling the dynamic characteristics of pneumatic muscle’, *Annals of Biomedical Engineering*, 13(3), pp. 310–317. doi: https://dx.doi.org/10.1114/1.1554921.

Robertson, M. A. and Paik, J. (2017) ‘New soft robots really suck : Vacuum-powered systems empower diverse capabilities’, *Science Robotics*, 2(9), pp. 1–12. doi: https://dx.doi.org/10.1126/scirobotics.aan6357.

Shepherd, R. *et al.* (2011) ‘Multigait soft robot’, in *Proceeding of the National Academy of Sciences of the United Stated of America*, pp. 20400–20403. doi: https://dx.doi.org/10.1073/pnas.1116564108.

Tawk, C. *et al.* (2018) ‘Bioinspired 3D Printable Soft Vacuum Actuators for Locomotion Robots, Grippers and Artificial Muscles’, *Soft Robotics*, 5(6), pp. 685–694. doi: 10.1089/soro.2018.0021.

Tawk, C., Spinks, G. M. and Alici, G. (2019) ‘3D Printable Linear Soft Vacuum Actuators : Their Modeling , Performance Quantification and Application in Soft Robotic Systems’, *IEEE/ASME Transactions on Mechatronics*, 24(5), pp. 2118–2129.

Vasios, N. *et al.* (2019) ‘Harnessing Viscous Flow to Simplify the Actuation of Fluidic Soft Robots’, 00(00), pp. 1–9. doi: 10.1089/soro.2018.0149.

Wang, C. *et al.* (2019) ‘Correlation of tribological behavior and fatigue properties of filled and unfilled TPUs’, *Lubricants*, 7(7). doi: 10.3390/lubricants7070060.

Yang, D. *et al.* (2016) ‘Buckling pneumatic linear actuators inspired by muscle’, *Advanced Materials Technologies*, 1(3). doi: https://dx.doi.org/10.1002/admt.201600055.