A Study on Modular Design of End Effector

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Abstract— **In this paper, we present a study on modular end effector systems. As the available services of robots grow, robots need to carry out different tasks for various purposes. To carry out these tasks in different environments, flexibility and reusability of the robot system are the most important factors. Therefore, in this study we consider the three following conditions. First, the size of the end effector module is less than or equal to a regular adult male. Second, degrees of freedom of the end effector are easily added and removed according to a given task. Last, the end effector is configured as a master-slave-based control architecture to enable smooth control between each module. The manufactured end effector module is actuated by a wire-driven mechanism, and the end joint is configured as a three-axis load cell. Finally, an end effector is configured by combining three manufactured modules, and experiments are conducted to evaluate the performance.**

I. INTRODUCTION

Recently, as the available services of robots grow, robots need to carry out different tasks for various purposes. According to this trend, the robot system is required to be flexible and reusable for different tasks and work environments. Already robot manipulator, a user by combining the modular joint, cases be composed of robot for your application is increasing [1-5]. Naturally, the study of end effectors has rapidly progressed in response to this. Due to advances in technology, end effector research has heavily focused on the anthropomorphic type of gripper, which mimics the human hand [7-8]. However, the robot is most efficient to apply to suitable end effector for the given tasks. Depending on the combination of modular end effector configured to the suitable end effector for a given task, it will be the most efficient work. In this paper, we propose a modular end effector that is combined with the base of another end effector.

A. Backgrounds

The modularity of robots has been a key issue in the development of service robots for application in various fields. Thus, research on this topic has been conducted by many organizations. Among them, Lee, H. D et al. [3] proposed improving the adaptability of robot mechanisms by using a modularized joint mechanism. These robotic systems are more flexible and move more quickly, while also having low costs for manufacturing and maintenance. Additionally, they have designed a modular type joint with one degree of freedom(DoF) for general purpose. Yan, J. et al. [4] proposed a single-DoF rotary joint module. This module is formed by combining the mechanical structure, drive module, control module and communication module into a single module, characterized by its compact size, light weight and large module torque. Moreover, using this module, users can assemble manipulators of different DoF and different configurations as needed. Accordingly, the study of robot manipulators currently focuses more heavily on modularity, including the modularity of end effectors. A. Izzo et al. [5] developed modular end effectors based on a compliant soft actuation system, which is able to provide gripping forces up to 5.78N; this end effector is able to ensure the desired requirements (in terms of generated forces) for application in the field of MIS (Minimally Invasive Surgery). Ma, Raymond R. et al. [6] proposed the design of an open-source, low-cost, under-actuated hand with a single actuator. This study establishes the design of an adaptive, four-finger hand utilizing simple 3D-printed components, compliant flexure joints, and readily obtainable off-the-shelf parts. However, these studies are limited in that most end effector modules are developed for a specific purpose. In other words, research on end effectors that are combined with modular end effectors is relatively small compared to other topics of research. In this paper, we introduce a combination of modular end effectors that can change its DoF depending on the task without any modification of the mechanism.

II. CONCEPT OF MODULAR END EFFECTOR

A. Condition of Design Specifications

End effectors should be actuated in the human work space. To accomplish this, they need to be able to add and remove DoF depending on the task at hand without any modification of the mechanism. Additionally, the end effector control system needs to be able to easily change its application in accordance with the change in DoF. For this, consider the following:

- The end effector should be suitable for human work space environments. Therefore, the size of the end effector module should be less than or equal to a regular adult male.
- The end effector type is different for each task. Therefore, the form of the end effector according to the combination of modules should be easily modified.
- The end effector should implement a small size actuator (ϕ 10-15 mm) located in the interior of the module. In addition, the system should be under-actuated in order to satisfy the light-weight and low-cost requirements.

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- Each module should be configured as a control architecture based on a master-slave configuration to enable smooth control between modules.

These specifications have been considered in the design of the proposed modular end effector, as described in Section II B.

B. Design of Modular End effector

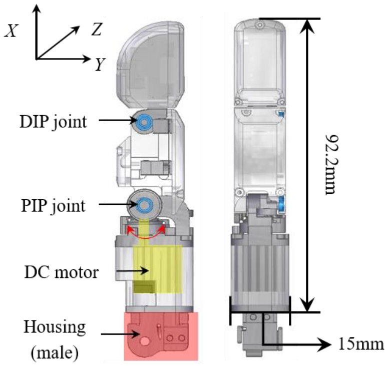


Figure 1. Concept design of the end effector module.

The proposed modular end effector has a length of 92.2mm and a width of 15mm, similar to that of a normal adult male. The end effector consists of both DIP and PIP joints, as shown in Figure 1 [9]. These two joints have 1 DoF each in the pitch direction. Thus, the configured end effector is operated by the built-in DC motor. Next, the under-actuated mechanism based on wire-driven actuated end effectors is implemented as a single DC motor. When the internal DC motor is operated, the wire around the pulley is pulled and both the DIP and the PIP joints bend simultaneously, as shown in Figure 2 [9].

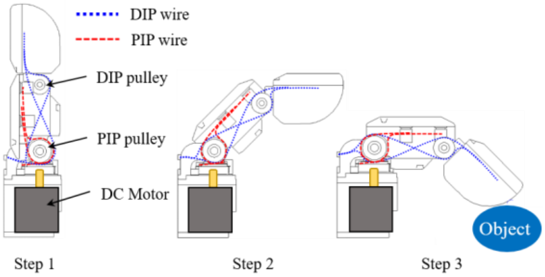
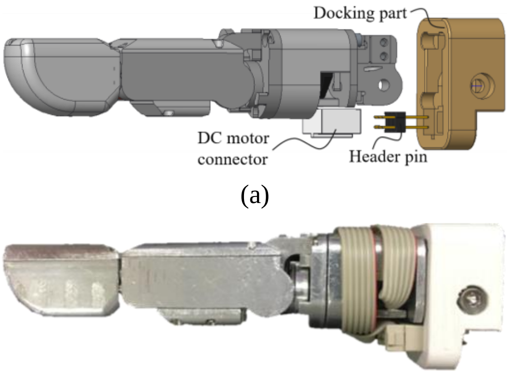


Figure 2. Moving motion of end effector module.

A docking part for the end effector base should then be combined with the modular end effector. The proposed docking part is fixed to the housing (male) part, which is configured to the end effector module to enable easy replacement. The docking part also has a header pin, which allows for easy connection to the DC motor. Thus, when combined with the base, this enables motor control without the use of additional elements. 3D modeling of the proposed docking part and end effector module are shown in Figure 3a, and the prototype of the end effector module is shown in Figure 3b. Note that the prototype was manufactured using a 3D printer. The physical dimensions of the end effector module combined with the docking part are as follows: a maximum length of 107.2mm, a maximum width of 21mm, and a weight of 60g. Figure 5 shows different types of end effectors according to the combination used.



(a)

(b)

Figure 3. Components of the docking system: (a) 3D model of the docking system and (b) combine docking system with modular end effector.

If the end effector module is pressing against an object, this force needs to be measured. Thus, the end joint of the modular end effector is designed as a three-axis load cell (force sensor), and a strain gauge is bonded to its surface, as shown in Figure 4 [9]. When a load is applied to the load cell, the binocular structure of the load cell deforms and the output reading of the strain gauge changes. The specifications of the strain gauge are as follows: a thickness of 0.03mm, a resistance of 120.4 (±0.5)Ω, and a gauge factor of 2.35(±2)%. Figure 4 shows the manufactured three-axis load cell (left) and a strain gauge bonded to each direction surface of the load cell (right).

Figure 4. Manufactured three axis load cell.

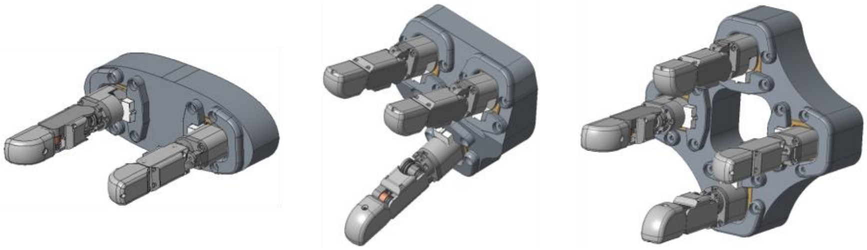


Figure 5. Example of various end effector according to the number of end effector modules.

C. Concept of Communication System

The modular end effector is formed according to the combination modules. Thus, the control system should be configured using a master-slave-based control architecture for efficient control between each module. This is described in Figure 6. The control architecture is configured as follows: a master node (host PC), slave nodes (micro controller unit, MCU) to enable direct control of the end effector modules, and sub-master nodes (single board PC, raspberry Pi, Odroid, etc.) for overall management. The master node acts as an overall manager of each sub-master node, and it generates a control command for the current task of the robot (which is configured a module unit). The control commands for the sub-masters are transmitted via wireless communications (TCP/IP). The sub-master node directly controls each slave node. Thus, using the command signal received by the master node and the feedback signal from the device connected to the slave node, the sub-master node transmits the control command to the MCU. The slave nodes are connected to the DC motor and the force sensor of the modular end effector, and it transmits data for the motor encoder value and force sensor to the sub-master node. At this time, the sub-master node and slave node communicate via RS-232.

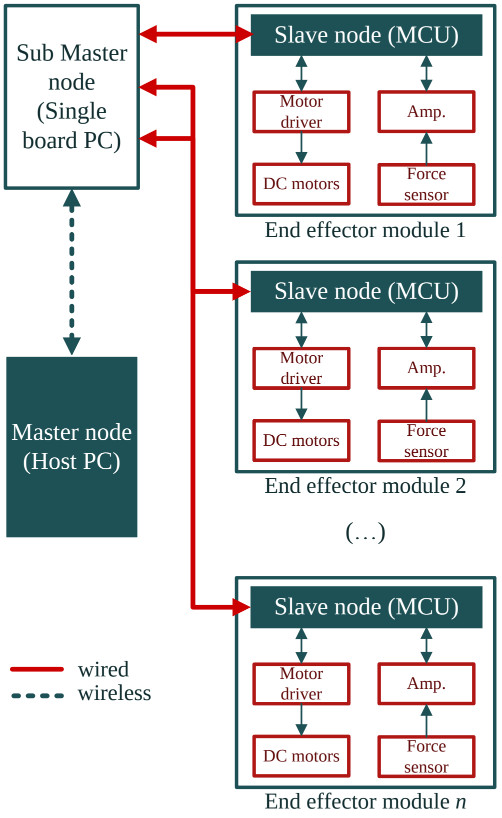


Figure 6. Flow chart of control architecture for the master-slave configuration.

III. TESTS ON THE MODULAR END EFFECTOR

In this chapter, we evaluate the performance of the proposed modular end effector. The performance evaluation is conducted using force measurements of the modular end effector, and the manipulation performance of the gripper is also evaluated.

A. End Effector Module Force Evaluation

Commercial four-line load cells are used for the force measurement of the end effector module. The test environment is fixed the load cell and the end effector module on different vise as shown Figure 7. The load cell and end effector module are connected with a wire in order to measure the force. The load cell output (kg) can be seen through a commercial indicator. The rated voltage of the DC motor is 12V. However, the performance was evaluated in 1V increments from 12V to 24V to observe how the end effector force behaves relative to the input voltage. The result is shown in Figure 8, indicating that the end effector force increases approximately linearly according to the input voltage.

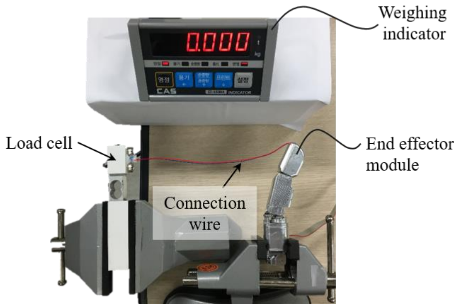


Figure 7. Method for force measurement for the end effector module.

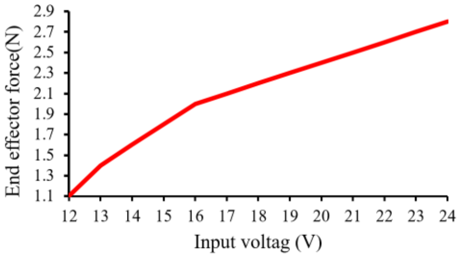


Figure 8. End effector module force according to input voltage.

B. Three Axis Force Sensor Evaluation

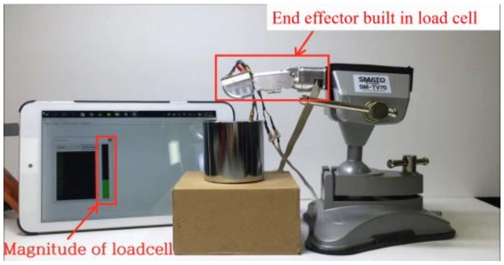
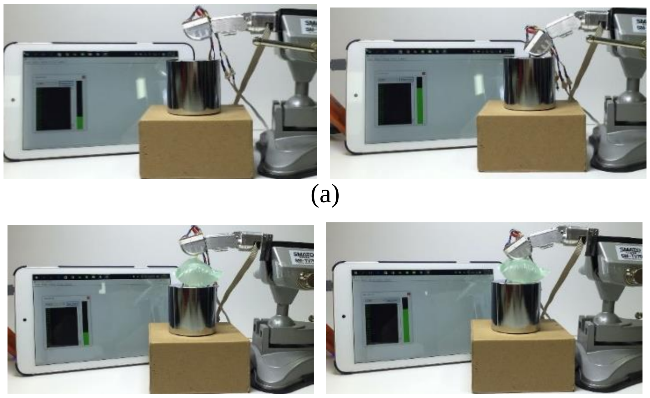


Figure 9. Experiment enviroment for output check of load cell.

We should also observe the output of the manufactured three-axis load cell. The manufactured load cell is used to possible pass the process such as temperature compensation, calibration of the strain gauge. In this chapter, we introduce an output check process for the designed three-axis load cell system, as shown in Figure 9 [9]. At every scheduled time, the MCU transmits the amplification value of the three-axis load cell to the GUI program (PC) with the RS-232 communication. In this test program, the real-time value of the load cell is expressed using a text and graphic interface. At the moment the test object is the strong object and the elastic object for the performance evaluation. When the modules press against each of the two objects, the magnitude of the force can be verified via the test program. This signifies that the designed load cell system is acting normally.

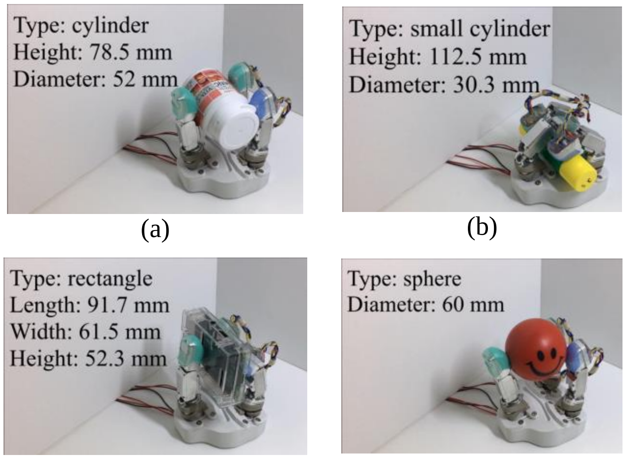

(a)

(b)

Figure 10. Result of the load cell experiment: (a) hard object and (b) elastic object.

C. *Various Grasping Postures*

In this section, the grasping evaluation for the manipulation performance of the gripper is carried out. The shape of the object is simple: either a cylinder, small cylinder, rectangle, or sphere. The size of each object is shown Table 1. The results indicate that the gripper consisting of three modules is able to successfully grasp each of the various objects, as shown Figure 11.



(a) (b)

(c) (d)

Figure 11. Result of various grasping postures: (a) cylinder type, (b) small cylinder type, (c) rectange type, and (d) sphere type.

TABLE I. THE SIZE OF EACH OBJECT

Type	**Size (mm)**
Cylinder	height: 52.3, diameter: ϕ 52
Small cylinder	height: 112.5, diameter: ϕ 30.3
Rectangle	length: 91.7, width: 61.5, height: 52.3
Sphere	diameter: ϕ 60

IV. DISCUSSION AND CONCLUSION

In this paper, we propose a new modular end effector. The proposed end effector focuses on both the flexibility and reusability as a core for the modularity. Thus, we developed a modular end effector based on a wire-driven mechanism and DIP/PIP joints. For the docking part of the end effector base, we enabled easily added and removed degrees of freedom. Also, we implemented a three-axis load cell at the end joint that can measure the force when the modular end effector presses against an object. The control system has been configured as a master-slave-based control architecture to efficiently control each module. The measured forces of the developed modular end effector are as follows: 1.1N at 12V (rated voltage) and 2.8N at 24V. Experiments show that the three-axis load cell system acts normally when pressing against an object. Last, the gripper consists of three modules that are able to grasp various objects. However, present three axis load cell should be passed the temperature compensation, calibration. Additionally, the modular end effector should be able to apply a larger force in order to stably grasp heavy objects.

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REFERENCES

[1] Hong, Seonghun, et al. "Design of manually reconfigurable modular manipulator with three revolute joints and links." 2016 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2016.

[2] Lin, Yunhan, Huasong Min, and Hongxing Wei. "Inertial measurement unit–based iterative pose compensation algorithm for low-cost modular manipulator." Advances in Mechanical Engineering 8.1 (2016): 1687814015626850.

[3] Lee, Hee-Don, and Chang-Soo Han. "Design of a Modular Type Joint Mechanism for a Service Robot." Journal of the Korean Society for Precision Engineering 28.11 (2011): 1272-1278.

[4] Yan, Jihong, et al. "A modular manipulator system using rotary joints toward helping the elderly and the handicapped." Robotics and Biomimetics (ROBIO), 2014 IEEE International Conference on. IEEE, 2014.

[5] Izzo, A., et al. "Design, development and characterization of a modular end effector for MIS procedures." 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). IEEE, 2015.

[6] Ma, Raymond R., Lael U. Odhner, and Aaron M. Dollar. "A modular, open-source 3D printed underactuated hand." Robotics and Automation (ICRA), 2013 IEEE International Conference on. IEEE, 2013.

[7] Salerno, Marco, et al. "A Novel 4-DOFs Origami Enabled, SMA Actuated, Robotic End-Effector for Minimally Invasive Surgery." Robotics and Automation (ICRA), 2014 IEEE International Conference on, Hong Kong, May 2014, pp. 2844-2849.

[8] Deimel, Raphael, and Oliver Brock. "A novel type of compliant and underactuated robotic hand for dexterous grasping." The International Journal of Robotics Research (2015): 0278364915592961.

[9] Park, Hyeonjun, Bumjoo Lee, and Donghan Kim. "Violin Musical Tone Analysis Using Robot Finger." Procedia Computer Science 94 (2016): 398-403.