

절단과 파지 기능을 통합한 단일 모터 구동형 고추 수확 그리퍼 메커니즘

Single-Motor Driven Horn Pepper Harvesting Gripper Mechanism Integrating Cutting and Grasping

강효재¹·김희준²·최인규¹·이왕건¹·강민성[†]

HyoJae Kang¹, HeeJun Kim², InGyu Choi¹, WangGeon Lee¹, Min-Sung Kang[†]

Abstract: Agricultural robotics technology has greatly contributed to increasing productivity and reducing labor, with harvest automation being one of the key innovations in the agricultural sector. This study focuses on designing a miniaturized gripper for the efficient harvesting of horn peppers. The proposed gripper grasps the stem of the horn pepper without contacting surrounding crops and simplifies the harvesting process by allowing the stem to be cut through continued actuation after grasping. This minimizes crop damage during harvesting and enables simultaneous grasping and cutting with a single actuator. Additionally, instead of using mechanical components like springs, the gripper integrates EVA foam for a simple structure. Experiments demonstrated that the proposed gripper successfully grasps and cuts the stem of horn peppers. This study introduces a gripper that can contribute to the automation of agricultural harvesting, with potential applicability to a variety of pepper-like crops.

Keywords: Gripper, Grasping, Harvesting Robot, Mechanism Design

1. Introduction

The advancement of robotic technology has significantly impacted various industries, including manufacturing, health-care, logistics, and services. Among these, the agricultural sector has seen rapid changes with the introduction of robots, leading to increased productivity and reduced labor costs. In particular, the aging population and the growing labor shortage in agriculture have highlighted the necessity for automation through robotic solutions. Agricultural robots are now utilized for tasks such as

seeding^[1], weed control^[2], harvesting^[3], crop picking^[4], irrigation^[5], fertilizing^[6], and crop monitoring^[7].

Among these tasks, harvesting automation stands out for its potential to enhance farmers' productivity, which can have a broad positive impact on society^[3,8]. Harvesting robots must be capable of recognizing crops in various environments and focus on harvesting them without causing damage. These robots are typically composed of a mobile platform capable of navigating through fields, an arm that can approach crops from the edges of the field, and a gripper designed to harvest crops. In some systems, additional devices are used to store harvested crops, or wire-based systems are employed to move along the field and carry out the harvesting process.

A critical challenge in harvest automation is preventing crop damage during the harvesting process. Damage can directly affect the market value of the crops and threaten the sustainability of agricultural practices. Many crops have delicate surfaces, requiring smooth and gentle handling^[9]. Existing

Received : Nov. 4. 2024; Revised : Jan. 3. 2025; Accepted : Mar. 4. 2025

※ This research was supported by a grant (D2410002) from Gyeonggi Technology Development Program funded by Gyeonggi Province.

1. Researcher, Department of Interdisciplinary Robot Engineering System, Hanyang University, Ansan, Korea (majaae5, chkchk123, dldhkdjrs2@hanyang.ac.kr)

2. Researcher, School of Smart Convergence Engineering, Hanyang University, Ansan, Korea (heejun@hanyang.ac.kr)

† Associate Professor, Corresponding author: School of Smart Convergence Engineering, Hanyang University, Ansan, Korea (wowmecha@hanyang.ac.kr)

harvesting grippers are generally categorized into two types: those that perform both cutting and gripping^[10,11], and those that grip the crop without cutting and harvest by shaking or pulling^[12]. Various studies have been conducted on these approaches for different crops.

This study focuses on designing a gripper specifically for harvesting horn peppers, a crop that presents unique challenges. Since a single horn pepper plant produces multiple peppers, it is essential to avoid damaging nearby growing crops while harvesting only the ripe ones. Conventional grippers face challenges in this context, as they are prone to touching and damaging surrounding crops. Directly gripping the crop can cause further damage, and while soft grippers could be a solution, they are costly and more difficult to control than electric grippers. Moreover, grippers that harvest by shaking or pulling the crop risk damaging the stem, which can lead to water entering the crop during the cleaning process, thereby reducing its market value.

To address these issues, this study proposes a compact gripper designed specifically for horn pepper harvesting, minimizing contact with surrounding crops and gripping only the stem of the target pepper. The gripper integrates both gripping and cutting functions into a single actuator, simplifying the harvesting process. By combining these functionalities, the proposed gripper aims to maintain the crop's market value while simplifying control mechanisms.

In the following sections, we review existing studies on harvest grippers and explain the design of the proposed gripper. Section 3 discuss the gripping and cutting mechanisms, Section 4 describe experiments conducted on horn pepper harvesting, and Section 5 present the conclusions and contributions of this research.

2. Related Works

Robotic grippers for harvest automation have been studied for various crops. In particular, soft grippers have been extensively researched to prevent damage to the surface of crops during the gripping process. These soft grippers have been implemented in various forms, such as three-finger^[13], two-finger^[9], and pneumatic systems that inflate materials to gently wrap around the fruit^[14]. Other methods include using suction cups^[15] and rigid grippers^[16] that grip and cut the stem.

Although grippers have been developed for a wide range of crops, this study focuses on the harvesting of horn pepper. There are various types of peppers, and many studies have been conducted on sweet pepper harvesting^[17-19]. However, there are several challenges in applying sweet pepper grippers to horn peppers. Sweet peppers, like tomatoes, have a round shape, whereas horn peppers are thin and elongated. Moreover, horn peppers are smaller in size, increasing the risk of damaging surrounding crops when using conventional grippers. Additionally, research on horn pepper harvesting^[20] shows that shaking the pepper after gripping can lead to crop damage.

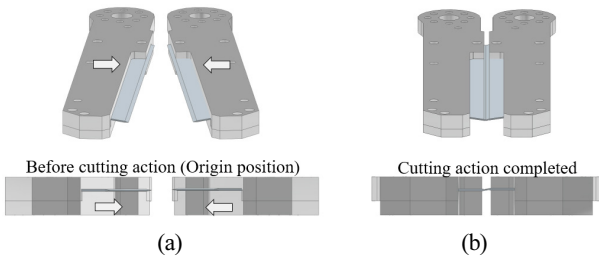
Studies have also investigated ways to cut the stem without directly touching the crop^[15,16]. Both studies used a single actuator to operate scissors and fingers simultaneously. However, in study^[16], the lack of a pressing function for the fingers poses a risk of damaging the stem during the cutting process. In study^[15], a spring and additional mechanical structures were required for pressing and returning functions, which resulted in a more complex structure. Moreover, the rigid gripper could cause damage when contacting the stem.

Thus, this study proposes a gripper that uses Ethylene Vinyl Acetate (EVA) Foam to enable soft contact, with a simple structure that allows both gripping and cutting using a single actuator. This approach aims to minimize damage to surrounding crops, improve marketability by efficiently gripping and cutting the stem, and simplify control mechanisms.

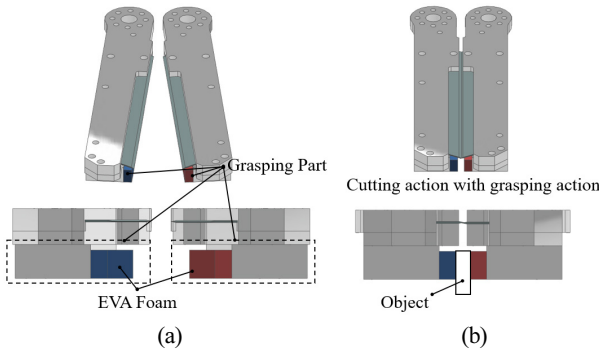
3. Gripper Mechanism Design

This section presents the mechanism of a gripper designed to grasp and cut stems that are less related to the marketability of the crops. As explained in the previous section, the gripper is designed to grasp only the stem of the crop, which allows for a smaller gripping device and minimizes contact with surrounding crops. Additionally, the cutting mechanism is integrated with the gripping mechanism and operates using a single motor.

First, the cutting mechanism for crop harvesting is described. [Fig. 1] shows the initial position of the cutting device and its state after the cutting action. The device mainly consists of a frame to hold the blades and the blades themselves. The blades used are replaceable blades (BA1P, NT Cutter) typically found in standard cutters. This design allows for easy blade replacement when they become dull. The blade thickness is 0.38 mm, and



[Fig. 1] Cutting device structure (a) at the initial position and (b) after cutting action is completed

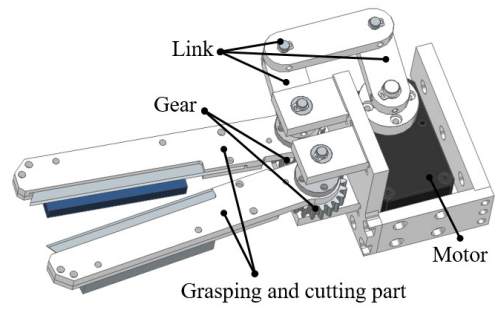


[Fig. 2] (a) Structure of the grasping part with attached EVA foam and (b) object grasping with EVA foam during the cutting action

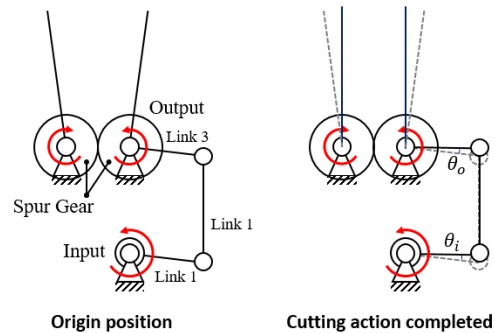
they are installed with a 0.1 mm offset between the top and bottom blades. Additionally, the cutting mechanism ensures cutting performance by allowing the two blades to intersect, as shown in [Fig. 1(b)].

Next, the gripping function is explained. Previous studies have used spring and linkage structures or forced compression to achieve gripping. In the proposed design, as shown in [Fig. 2(a)], EVA foam is mounted on an aluminum block, and this structure is attached to the gripping device. The two pieces of EVA foam achieve gripping through compression of the object as illustrated in [Fig. 2(b)]. EVA foam is highly resilient and provides a soft contact surface, preventing damage to the stem of the crop being gripped. Additionally, the structure is mounted below the cutting device, allowing the lower part of the crop stem to be gripped while the upper part is cut. This enables simultaneous gripping and cutting.

The proposed cutting device integrating the gripping function, is designed to be driven by a single actuator for simplified control. [Fig. 3] illustrates the overall structure of the gripper. The gripper employs a one by one ratio spur gear to drive the two shafts of the cutting and gripping devices in opposite directions. Each gear is coupled with the shaft of the cutting device,



[Fig. 3] Isometric view of proposed gripper



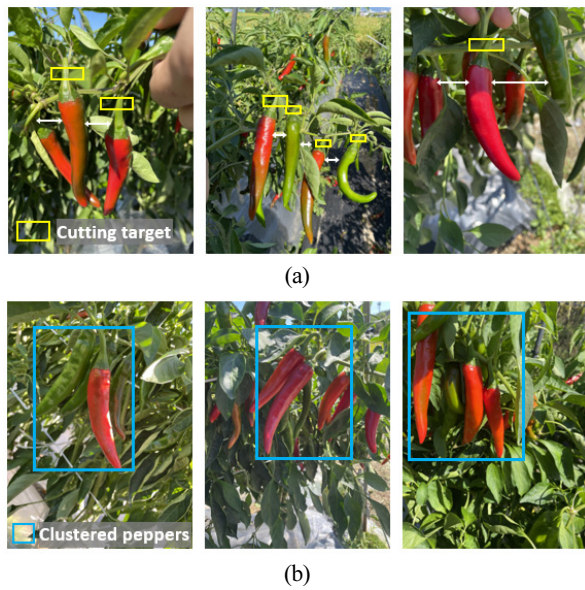
[Fig. 4] Kinematic diagram of gripper link mechanism

allowing the end of the link to rotate by the same angle as the shaft. [Fig. 4] shows this linkage structure. Starting from the origin position, there is an input joint corresponding to the actuator, and the power is transmitted through three links. When the input rotates by θ_i for the cutting action from the initial position, the output shaft rotates by θ_o . Since Link1 and Link3 have the same length and are parallel, the two angles are equal.

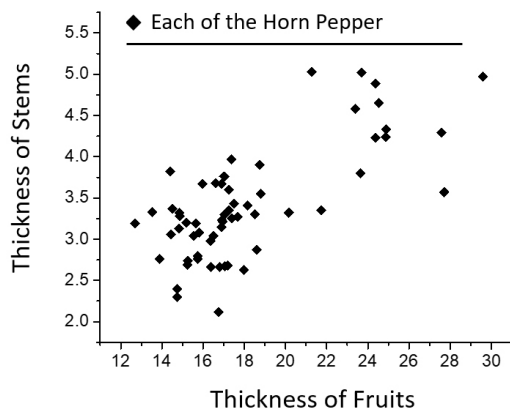
The proposed gripper can perform both cutting and gripping functions for harvesting by operating a single motor. It is designed using readily available blades and EVA foam, which can be easily replaced, allowing for continuous use. Additionally, the size of the entire device can be adjusted by modifying the length of the cutting mechanism and the links, making it more adaptable for size variations compared to traditional tools.

4. Experiment

Before conducting the experiment, we compared the size of the gripper and horn peppers to determine whether the gripper touched non-target crops. This comparison helped predict whether the gripper would interfere with the surrounding crops when approaching to harvest the horn pepper. Next, experiments were conducted on the stems of ten horn peppers to test the



[Fig. 5] Crop harvesting environment (a) horn peppers spaced apart, (b) Densely Packed



[Fig. 6] Scatter data of the sizes of 60-horn peppers used in the experiment

gripper’s gripping and cutting functions. Through this process, the performance of the gripper was evaluated.

The gripper used in the experiment is equipped with a servo motor (Robotis, XM430-W350-T), which is connected to the PC via a communication converter (Robotis, U2D2). Additionally, the motor’s power is supplied through a power supply unit.

First, before comparing the gripper size to that of the horn pepper, the actual harvesting environment is examined. [Fig. 5] shows the real harvesting environment of red horn peppers. In [Fig. 5(a)], it can be observed that even though the peppers are densely packed, they are still distinctly separated from each other. The goal is to cut the section marked by the yellow rectangle for the harvest of such peppers. [Fig. 5(b)] shows a

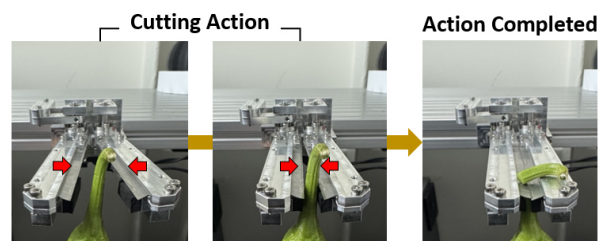
more densely packed arrangement of peppers compared to [Fig. 5(a)], where some peppers are in direct contact with one another. Even when the peppers are touching, they are not perfectly parallel, meaning the required width of the gripper fingers may vary depending on the approach angle. In this study, commercially available green peppers were purchased, and it was determined that if the gripper finger width is smaller than the average diameter of these peppers, the gripper is deemed suitable for the task.

The experiment utilized a total of 60 horn peppers, each varying in size. [Fig. 6] presents the data on the dimensions of these 60 horn peppers. In the graph, the x-axis represents the maximum thickness of the flesh portion, while the y-axis represents the maximum thickness at the position where the gripper’s foam can be placed without grasping the flesh. The average thickness of the flesh is 18.17 mm, and the average thickness of the stem is 3.41 mm. The thickness of the flesh ranges from 12.7 mm to 29.58 mm, while the thickness of the stem ranges from 2.12 mm to 5.03 mm. [Fig. 7] illustrates an example where the thickest parts of two peppers are tied together to check whether the gripper can fit between the stems. This experiment confirmed that the gripper can indeed enter between the pepper stems.

Next, to validate the performance of the gripper, a grasping and cutting experiment was conducted. For this performance validation, the gripper was fixed in place while the horn peppers



[Fig. 7] The gripper finger insertion between close pepper stems



[Fig. 8] Grasping and cutting action of the gripper



[Fig. 9] Images of the horn pepper (a) before and (b) after the gripper experiment

were brought to the gripper, which was then activated to check its functionality. [Fig. 8] illustrates the process of the gripper performing grasping and cutting simultaneously. The opening distance of the gripper was set so that the gap between the blade tips matched the average thickness of the pepper flesh. This procedure was followed consistently throughout the experiment.

[Fig. 9] shows the images of the horn peppers before and after cutting, following the process described in [Fig. 8]. [Fig. 9(a)] presents an image taken before the experiment, while [Fig. 9(b)] shows the result after the experiment. From the results of all 60 peppers, it can be observed that the cutting edges were cleanly severed. Also, the time required for the gripper to complete grasping was measured in 50 ms increments, and in all cases, the process was completed within 150 ms.

The experimental results identified two key requirements for the gripper to successfully harvest horn peppers. First, as mentioned in [Fig. 7], the minimum dimension required for the gripper to pass between the stems of the peppers is described. Based on this standard, the functionality of the gripper was validated through experiments. Additionally, the harvesting range determined by the experimental results was confirmed to be up to 5.03 mm, based on the stem dimensions.

5. Conclusion

In this study, we propose a method to replace existing grippers by utilizing the characteristics required for a gripper specifically designed for harvesting horn peppers. To prevent the gripper from touching non-target crops, the gripper grasps and cuts the stem of less market-relevant crops. Additionally, by integrating the grasping and cutting functions into a single actuator, the gripper simplifies operations, allowing for unified task execution and easier control.

The proposed gripper can be extended not only to horn peppers but also to similar crops. For instance, in the case of bell peppers, it can be applied by adjusting the gripping force to accommodate the weight of the crop, ensuring no issues with gripping. Furthermore, by adjusting the gripping force and cutting function, the gripper can harvest crops without directly grasping areas related to market value. This versatility allows for application to a wide range of crops, contributing to the automation of agricultural harvesting.

In this study, the gripper fingers were designed to minimize contact with surrounding peppers during the harvesting process by ensuring they could fit between the stems. The gripper size was compared using the diameters of commercially available peppers, and its performance was validated through experiments on gripping and cutting the actual pepper stems. Additionally, the cut surfaces of the stems were presented to demonstrate the cutting performance of the gripper.

References

- [1] A. B. Tatar, A. K. Tanyıldızı, and B. Taşar, "A Conceptual Design of Two DoF Crawler Tree Planting Robot with Helical Digging Arm," *2023 14th International Conference on Mechanical and Intelligent Manufacturing Technologies (ICMMIT)*, Cape Town, South Africa, pp. 8-11, 2023, DOI: 10.1109/ICMIMT59138.2023.10201123.
- [2] J. Ju, G. Chen, Z. Lv, M. Zhao, L. Sun, Z. Wang, and J. Wang, "Design and experiment of an adaptive cruise weeding robot for paddy fields based on improved YOLOv5," *Computers and Electronics in Agriculture*, vol. 219, Apr., 2024, DOI: 10.1016/j.compag.2024.108824.
- [3] V. Raja, B. Bhaskaran, K. Nagaraj, J. Sampathkumar, and S. Senthilkumar, "Agricultural harvesting using integrated robot system," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 25, no. 1, 2022, DOI: 10.11591/ijeecs.v25.i1.pp152-158.

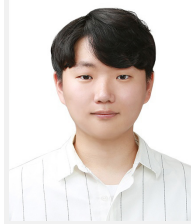
- [4] A. R. Syafeeza, N. A. Hamid, M. L. Eng, G. W. Lee, H. J. Thai, and A. N. Amsan, "Robotic arm gripper using force sensor for crop picking mechanism," *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, vol. 14, no. 4, pp. 11-15, 2022, DOI: 10.54554/jtec.2022.14.04.002.
- [5] J. Li, J. Zhang, Z. Liu, Y. Liang, Z. Yin, and F. Wang, "Design of automatic irrigation robot based on tracking and visual recognition," *International Journal of Frontiers in Engineering Technology*, vol. 5, no. 4, 2023, DOI: 10.25236/IJFET.2023.050408.
- [6] A. S. A. Ghafar, S. S. H. Hajjaj, K. R. Gsangaya, M. T. H. Sultan, M. F. Mail, and L. S. Hua, "Design and development of a robot for spraying fertilizers and pesticides for agriculture," *Materials Today: Proceedings*, vol. 81, pp. 242-248, 2023, DOI: 10.1016/j.matpr.2021.03.174.
- [7] Z. Al-Mashhadani and J.-H. Park, "Autonomous agricultural monitoring robot for efficient smart farming," *2023 23rd International Conference on Control, Automation and Systems (ICCAS)*, Yeosu, Republic of Korea, pp. 640-645, 2023, DOI: 10.23919/ICCAS59377.2023.10316866.
- [8] L. Comba, P. Piccarolo, and D. R. Aimonino, "Robotics and automation for crop management: trends and perspective," *International Conference on Work Safety and Risk Prevention in Agro-food and Forest Systems*, Ragusa, Italia, pp. 471-478, 2010, [Online], [https://www.ragusashwa.it/CD_2010/lavori/TOPIC4/orale/Robotics_Gay\[1\].pdf](https://www.ragusashwa.it/CD_2010/lavori/TOPIC4/orale/Robotics_Gay[1].pdf).
- [9] A. Kultongkham, S. Kumnon, T. Thintawornkul, and T. Chanthasopeephan, "The design of a force feedback soft gripper for tomato harvesting," *Journal of Agricultural Engineering*, vol. 52, no. 1, 2021, DOI: 10.4081/jae.2021.1090.
- [10] Y. Park, J. Seol, J. Pak, Y. Jo, J. Jun, and H. I. Son, "A novel end-effector for a fruit and vegetable harvesting robot: mechanism and field experiment," *Precis. Agriculture*, vol. 24, no. 3, pp. 948-970, Dec., 2022, DOI: 10.1007/s11119-022-09981-5.
- [11] Z. Yu, J. Yuan, D. Guo, L. Du, S. Bao, and S. Ma, "Under-actuated Picking Gripper for Grasping and Cutting Citrus," *2021 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, Sanya, China, pp. 1935-1940, 2021, DOI: 10.1109/ROBIO54168.2021.9739289.
- [12] S. H. Shah, M. Arsalan, S. G. Khan, M. T. Khan, and M. S. Alam, "Design and compliance control of a robotic gripper for orange harvesting," *2019 22nd International Multitopic Conference (INMIC)*, Islamabad, Pakistan, pp. 1-5, 2019, DOI: 10.1109/INMIC48123.2019.9022758.
- [13] D. S. Choi, S. Y. Moon, and M. J. Hwang, "Improved design for enhanced grip stability of the flexible gripper in harvesting robot," *Journal of Korea Robotics Society*, vol. 15, no. 2, pp. 107-114, 2020, DOI: 10.7746/jkros.2020.15.2.107.
- [14] H. N. B. Ranasinghe, C. Kawshan, S. Himaruwan, A. L. Kulasekera, and P. Dassanayake, "Soft pneumatic grippers for reducing fruit damage during strawberry harvesting," *2022 Moratuwa Engineering Research Conference (MERCCon)*, Moratuwa, Sri Lanka, pp. 1-6, 2022, DOI: 10.1109/MERCCon55799.2022.9906289.
- [15] B. Jia, A. Zhu, S. X. Yang, and G. S. Mittal, "Integrated gripper and cutter in a mobile robotic system for harvesting greenhouse products," *2009 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, Guilin, China, pp. 1778-1783, 2009, DOI: 10.1109/ROBIO.2009.5420430.
- [16] N. R. Kolhalkar, V. Krishnan, A. A. Pandit, R. Somkuwar, and J. A. Shaaikh, "Design and performance evaluation of a novel end-effector with integrated gripper cum cutter for harvesting greenhouse produce," *International Journal of Advanced Technology and Engineering Exploration*, vol. 8, no. 84, Nov., 2021, DOI: 10.19101/IJATEE.2021.874507.
- [17] Z. Tasneem and K. Oka, "Design and performance analysis of soft pneumatic manipulator-based linear cutter and stem holder for sweet pepper harvesting," *Journal of Field Robotics*, vol. 41, no. 4, pp. 1204-1225, Jun., 2024, DOI: 10.1002/rob.22323.
- [18] C. W. Bac, J. Hemming, and B. A. J. Van Tuijl, R. Barth, E. Wais, and E. J. van Henten, "Performance evaluation of a harvesting robot for sweet pepper," *Journal of Field Robotics*, vol. 34, no. 6, pp. 1123-1139, Sept., 2017, DOI: 10.1002/rob.21709.
- [19] S. Bachche, K. Oka, and H. Sakamoto, "Design and modeling of gripper and cutting tool system for sweet pepper harvesting robot hand," *The 20th MAGDA Conference in Pacific Asia*, Kaohsiung, Taiwan, pp. 14-16, 2011, [Online], https://www.lab.kochi-tech.ac.jp/oka-lab/society/ron_pdf/okalab20111114_2A32.pdf.
- [20] L. Deng, T. Li, P. Jiang, A. Qi, Y. He, Y. Li, M. Yang, and X. Deng, "Design and testing of bionic-feature-based 3D-inted flexible end-effectors for picking horn peppers," *Agronomy*, vol. 13, no. 9, Aug., 2023, DOI: 10.3390/agronomy13092231.



강 효 재

2020 한양대학교 ERICA 로봇공학과(학사)
2022~현재 한양대학교 융합로봇시스템학과
석박사통합과정

관심분야: Gripper, Grasping, Robot mechanism design, Art and entertainment robot, and their applications



이 왕 권

2023 한양대학교 ERICA 로봇공학과(학사)
2023~현재 한양대학교 융합로봇시스템학과
석사과정

관심분야: Robot mechanism design, Harvesting robot, Legged wheel robot, Autonomous mobile robot



김 희 준

2023~현재 한양대학교 ERICA 스마트융합
공학부 학사 재학

관심분야: Gripper, Grasping, Robot mechanism design



강 민 성

1997 홍익대학교 기계공학과(학사)
2002 홍익대학교 기계공학과(석사)
2013 한양대학교 메카트로닉스학과(박사)
2013~현재 한양대학교 부교수

관심분야: Robot manipulator control, Robot mechanism design, Autonomous mobile robot, Construction robot, Computer vision, and their applications



최 인 규

2024 한양대학교 ERICA 스마트융합공학부
(학사)
2024~현재 한양대학교 융합로봇시스템학과
석사과정

관심분야: Robot planning and control, Harvesting robot