ICRA2026 Late Breaking Results Poster presented at
2026 IEEE International Conference on Robotics and Automation (ICRA 2026)
June 1-5, 2026. Vienna, Austria

An Underactuated Robotic Gripper with Flowability and Variable Stiffness for Food Bin-Picking

Yitong Xue
Graduate School of Science and Engineering
Ritsumeikan University
Kusatsu, Shiga 525-8577, Japan
rr0115ph@ed.ritsumei.ac.jp

Zhongkui Wang
Department of Robotics
Ritsumeikan University
Kusatsu, Shiga 525-8577, Japan
wangzk@fc.ritsumei.ac.jp

***Abstract*—This paper presents a single-motor underactuated gripper with variable stiffness, designed for food bin-picking tasks. The gripper employs highly compliant fingers that can passively adapt to cluttered environments and enclose target objects. Upon grasping, tendon-driven actuation increases structural stiffness, enabling low-damage, error-tolerant manipulation. Experiments on a variety of food items demonstrate robust grasping performance and stable object handling.**

***Index Terms*—soft robotic gripper, variable stiffness, flowability, food handling, bin-picking**

I. INTRODUCTION

Automating food bin-picking is challenging because many items are soft and easily damaged, and cluttered piles make grasping sensitive to perception and positioning errors [1]. In addition to the target, surrounding food items can also be damaged by unintended contact and squeezing. Existing soft grippers reduce contact damage, but often still depend on accurate sensing and control in cluttered scenes [2], [3].

In this work, we present a thread-driven, single-motor underactuated gripper that combines flowability and variable stiffness for cluttered food handling. The fingers are initially ultra-compliant to passively slip into inter-object gaps and reduce disturbance to nearby items.

The contributions are: We present a soft gripper integrating flowability and variable stiffness for cluttered food bin-picking to reduce damage to both target and surrounding items. We design a beaded-finger structure that enables gravity-driven gap insertion and passive obstacle avoidance without precise depth information. We develop a single-motor underactuated mechanism that achieves both gripper closure and stiffness modulation, reducing hardware and integration costs.

II. GRIPPER DESIGN

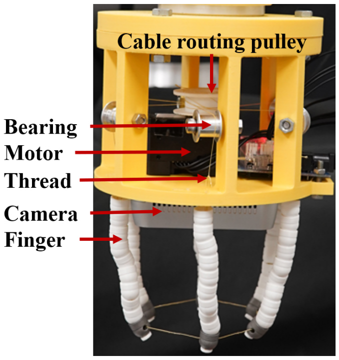
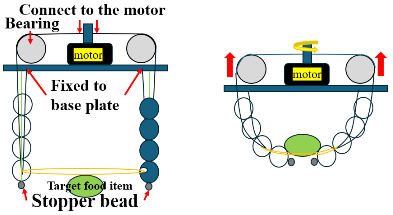


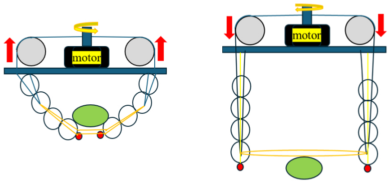
Fig. 1: Prototype of the proposed gripper with major components labeled.

The prototype of the proposed gripper is shown in Fig. 1. The system consists of a single motor, a motor-coupled rotating drum (spool/turntable), a tendon (thread) attached to the drum, an onboard camera, and compliant fingers. The tendon is routed through a cable-routing pulley and guided to the finger assembly, while the rotating shaft is supported by a bearing to ensure smooth winding/unwinding. A key feature of the proposed design is its underactuated actuation driven by one motor. As the drum rotates, the tendon length is regulated to first take up slack and close the finger loop for gentle enclosure of the target, and then further increase tendon tension to raise the effective finger stiffness for stable lifting. This single-motor mechanism simplifies the hardware and reduces integration cost, while enabling both grasp closure and stiffness modulation. The design and operating principle of the proposed gripper are summarized in Fig. 2. Fig. 2a depicts the initial configuration, which primarily illustrates the tendon layout and attachment points. The mechanism employs three threads (tendons). Thread 1 (T1, yellow) forms a loop at the fingertip level to connect the distal ends of all fingers. Thread 2 (T2, black) serves as the actuation thread: one end is fixed to the base plate, while the other end is driven by the motor; moreover, T2 is wrapped around T1 so that winding/unwinding T2 drives the motion of T1. Thread 3 (T3, green) is a retention thread: one end is fixed to the base plate and the other end is attached to a stopper bead, which prevents the finger beads from slipping off.

As shown in Fig. 2b, winding T2 retracts the tendons and pulls T3 into the finger, forcing the beaded fingers to bend inward and close around the target. After closure, further winding increases tension and drives the beads to press against the base plate (Fig. 2c), introducing compressive loading and thereby increasing the effective finger stiffness. Reversing the



(a) Initial (b) Closing



(c) Stiffening (d) Opening

Fig. 2: Working principle of the proposed gripper.

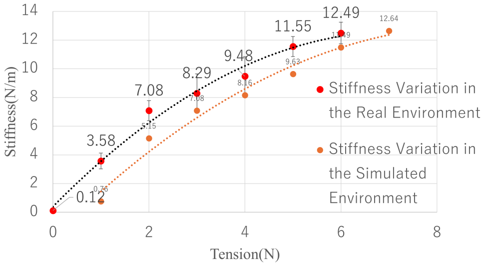


Fig. 3: Stiffness versus thread tension measured by the cantilever-beam test in the real setup and in MuJoCo simulation.

motor releases the tendons and the fingers return to the initial configuration under gravity (Fig. 2d).

III. STIFFNESS VARIATION EXPERIMENTS

To characterize the variable-stiffness capability, we conducted cantilever-beam stiffness tests in both a real setup and MuJoCo simulation. The finger was configured as a cantilever and subjected to a lateral load while varying the thread tension; the effective stiffness was obtained from the force-deflection relationship. The same procedure was replicated in MuJoCo with matched geometry and boundary conditions.

Fig. 3 plots stiffness versus thread tension. In both environments, stiffness increases monotonically with tension, indicating continuous stiffness tuning via single-thread actuation.

We further evaluated dynamic stability during fast robot motion using motion capture. A Universal Robots (UR) manipulator executed a high-speed motion (approximately 10 m/s) followed by an abrupt stop. Under the low-stiffness condition (no additional tension), the gripper oscillated after stopping and settled in about 1.7 s. With 5 N thread tension (high-stiffness condition), no obvious oscillation was observed and the gripper settled in about 0.4 s.

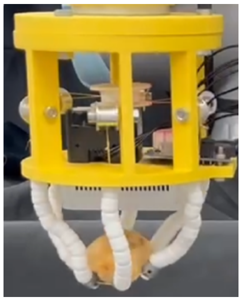


Fig. 4: Example grasping trial on a fried chicken piece with the proposed gripper mounted on the robot end-effector.

TABLE I: Grasping success rates for different food items (10 trials per item).

Food Item	**Success Rate**
Lemon	10/10
Fried chicken	10/10
Tomatoes	10/10
Bell peppers	8/10
Broccoli	10/10
Small taro	10/10
Sausage	10/10

IV. GRASPING EXPERIMENTS AND RESULTS

To evaluate the effectiveness of the proposed gripper in realistic food-handling scenarios, we conducted grasping experiments using a Universal Robots (UR) manipulator. The gripper was mounted on the robot end-effector, and multiple representative food items with different shapes and surface properties were tested.An example grasping trial is shown in Fig. 4. For each food item, 10 grasp attempts were performed under the same experimental procedure. A trial was counted as successful if the target item could be reliably grasped and lifted without dropping during the pick-and-lift process. The success rates for all tested food items are summarized in Table I.

Overall, the proposed gripper achieved 68 successful grasps out of 70 trials (97.1%). Failures were observed only for bell peppers (8/10), while all other items were grasped successfully in all trials. These results demonstrate that the proposed gripper can robustly handle a variety of food items and achieve high success rates in automated grasping tasks.

V. CONCLUSION

In this work, we presented a single-motor underactuated gripper with flowability and variable stiffness for food bin-picking. Experiments on a UR robot showed high success rates with low damage and improved stability under fast motions.

REFERENCES

[1] Z. Wang, S. Hirai, and S. Kawamura, "Challenges and opportunities in robotic food handling: A review," *Frontiers in Robotics and AI*, vol. 8, p. 789107, 2022.

[2] J. H. Low, P. M. Khin, Q. Q. Han *et al.*, "Sensorized reconfigurable soft robotic gripper system for automated food handling," *IEEE/ASME Transactions On Mechatronics*, vol. 27, no. 5, pp. 3232–3243, 2021.

[3] E. Brown, N. Rodenberg, J. Amend *et al.*, "Universal robotic gripper based on the jamming of granular material," *Proceedings of the National Academy of Sciences*, vol. 107, no. 44, pp. 18 809–18 814, 2010.