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Chobit Hand: a Gripper for a Linear-shaped Food Adjusting Precise Weight of Serving

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Abstract— **In many cases in the field of food processing and production, serving is still done by workers rather than by robots. However, linear foods such as spaghetti need to be served precisely and quantitatively, which is difficult for a conventional robot gripper. Therefore, in this study, we developed a new end-effector that can grasp a small amount of linear food with high accuracy. By installing several fingers on this end-effector and driving a fixed number of fingers according to the error between the target and the measured weight of food, we can compensate for the error. After investigating several parameters and selecting the optimal finger shape, the end-effector grasped one noodle with a success rate of nearly 90%. Next, we introduced capacitance sensors to all fingers to detect successful grasping. The sensors enabled us to construct a system that compensates for the weight errors in the amount of serving by detecting whether each finger is grasping and controlling the number of fingers that open accordingly. We conducted experiments with spaghetti and succeeded in adjusting the amount of food with an error of less than 2g.**

I. INTRODUCTION

Human workers serve manually in food processing and production processes[1]. These labors are harsh because they are performed for long hours in an enclosed space at low temperatures to maintain food quality. One of the reasons that robots have not replaced the work is that foods used for lunchboxes and side dishes are more flexible than other objects, and any damage to them significantly reduces their commercial value. In addition, since these foods vary in shape and size, it is difficult for robots to replace them in terms of speed, quantitativeness, and accuracy.

A prior example is the Tsummori Hand[2], developed by Endo et al. This hand can grasp a fixed amount of side dishes such as dried daikon radish and boiled hijiki (seaweed) and arrange them aesthetically in a conical shape. The Binding hand[3], developed by Hirai et al., is a hand with elastic threads stretched along the four fingers. The thread is retracted by closing the fingers, and the hand can grasp a plastic cup filled with food. The 3D printed soft gripper[4][5] uses an elastomer that bends when air pressure is applied as the material for the fingers and has succeeded in grasping not only food-filled cups but also uneven foods such as fried chicken and egg rolls. Matsuo et al. developed an AI robot[6] hand that can grasp shredded cabbage quantitatively using reinforcement learning. Two hundred training cycles in 2 hours resulted in a grasping error of 4.88 g on average against a target value of 50 g. Takahashi et al. defined entangled foods, such as shredded cabbage and bean sprouts, as foods that are difficult to grasp because they become entangled and lumpy, and attempted quantitative grasping[7]. By performing specific actions before and after grasping, they were able to reduce entanglement and adjust the amount of food to be grasped, and by using an RGB-D camera to photograph the tray from the top, they were able to estimate the gripper drop position at which the optimal amount of food could be grasped, and succeeded in significantly improving grasping accuracy. However, the robot hands mentioned above have a grasping error of about 10%, making it difficult to use them for precise adjustment of the amount of food.

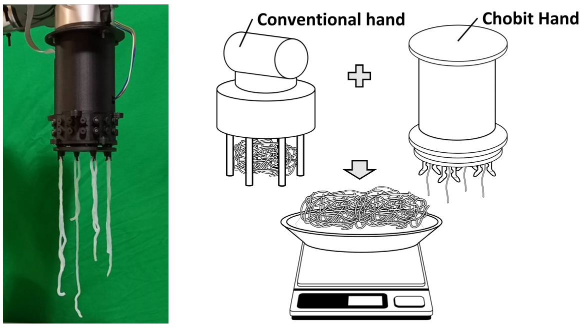

Fig. 1: Examples of "Chobit Hand" usage

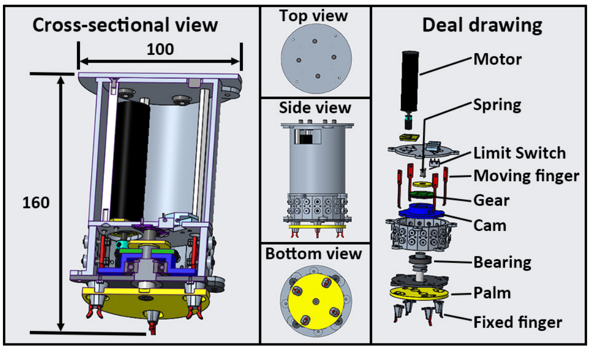

Fig. 2: Overall view and cross-sectional view of end-effector named "Chobit Hand"

This paper aims to realize a small and quantitative grasping of linear foods such as spaghetti by spatially restricting the grasping amount with a tiny grasping mechanism. As shown in Fig. 1, this grasping mechanism is intended to be used with manual techniques or with other types of robotic hands. The proposed robot hand, "Chobit Hand," achieves high precision serving by compensating for the error of a few grams. This paper is organized as follows. First, the

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structure and principle of the ”Chobit Hand,” an end-effector capable of accurately grasping a single spaghetti from a pile of spaghetti served in a container, are described. Next, we carried out grasping experiments using the Chobit Hand on actual food products, and the shapes of the finger and speeds at which the grasping accuracy improves will be discussed. Finally, an automatic weighing system that links Chobit Hand and a digital scale is described, and the results of operation tests are presented.

II. PROPOSAL OF END-EFFECTOR

A. *Overall end-effector configuration*

In this study, we propose a mechanism with multiple two-finger grasping mechanisms. The hand is a 1-DOF mechanism with a single actuator. The motor rotates a cam (Fig. 2, blue) via spur gears (Fig. 2, green). The concentric fingers (Fig. 2, red) are closed in response to the rotation of the cam. The fingers are removable, and up to eight fingers can be attached in the first prototyping. The cam shape can change the timing of finger closure. At the bottom of the hand is a palm (Fig. 2, yellow), which translates passively along the cam rotation axis. A spring normally presses the palm downward, and upward displacement of the palm occurs when the end-effector is pressed against the food. A limit switch detects the displacement when the end-effector is appropriately pressed against the food with a specific force. The proposed mechanism was designed based on the following considerations.

- The number of DOFs should be as small as possible.
- The number of fingers and timing of opening and closing can be adjustable according to the experiment.
- Usage of a rotational motion for ease of cleaning and waterproofing.
- A palm measures the food’s ever-changing height and increases the success rate of grasping by increasing the density of the food by pressing.

B. *Finger Mechanism*

As shown in Fig. 3, one of the two fingers is fixed to the inner wall, while the other is initially positioned by a coil spring and nut, and can be moved to the left or right. The actuator rotates a cam via spur gears to synchronously close the fingers, which narrows the fingers on the unfixed side until they are fully closed. The actuator reverses the rotation to drive the cam to open the fingers, which returns to its initial position by the restoring force of the coil spring. The cam shape modification can also return to the initial opening position with a one-way rotation.

III. SPAGHETTI GRASPING EXPERIMENT

A. *Preliminary Experiment*

In order to determine the basic shape of the finger, a preliminary experiment was conducted. A cap that restricts the grasping space was attached to the tip of an reverse action tweezers, and spaghetti was grasped. As a result, the spaghetti slid off the tweezers due to insufficient gripping force caused by the olive oil sprinkled on the spaghetti surface. Therefore, we considered that it would be difficult to stabilize the grasp with force closure, and we considered making a circular arc about the diameter of a piece of spaghetti on the finger for form closure. This shape can support the spaghetti from the underside while the fingers are closed; thus, a stable grasp can be expected.

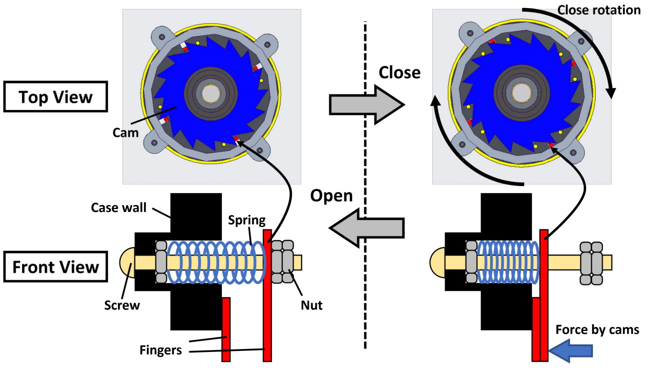


Fig. 3: Principle of finger opening and closing drive by cam and spring

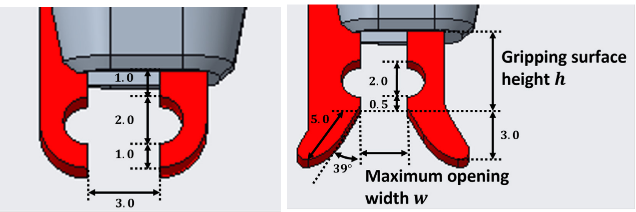
B. *Basic Finger Design and Comparison Experiment*

1) Experimental Method: Experiments were conducted to select a suitable finger shape for grasping a piece of spaghetti. As shown in Fig. 4, we tested two types of fingers: The Tapered type and the Spreading out type. As in the preliminary experiment, the Tapered type has a circular arc with a diameter equivalent to a piece of spaghetti for grasping with a form closure. Conversely, the Spreading out type has a widened lower part of the finger in addition to the arc. We adopted this shape because it is assumed that the spaghetti under the finger can be concentrated in the center of the finger, and the success rate of grasping increases. A conical holder encloses the fingers up to the palm and protrudes. We designed this shape because the gripper cannot be pressed into the spaghetti sufficiently when the protrusion height is insufficient. We also found that the square shape holder damages the spaghetti.

Two sets of fingers of the same shape were attached to the end-effector, and we measured the number of pieces of spaghetti grasped by each finger separately. The end-effector was attached to the tip of a cooperative robot UR5e (Universal Robot). The physical properties of the spaghetti used are shown in TABLE I. We performed a series of measurements 40 times for each shape and obtained 80 data. Fig. 5 shows snapshots of the experiment taken every 5 seconds. The cycle time for the entire trial was approximately 25 seconds. Each finger opening and closing took 5 seconds, and the remaining 15 seconds were for the descent, ascent, and lateral movement of the end-effector.

TABLE I: Physical properties of spaghetti

	Weight	Length	Diameter	Coating
Spaghetti	1.8 g (ave.)	300 mm (ave.)	2.3 mm	Olive oil



(a) Tapered type (b) Spreading out type

Fig. 4: Finger shape

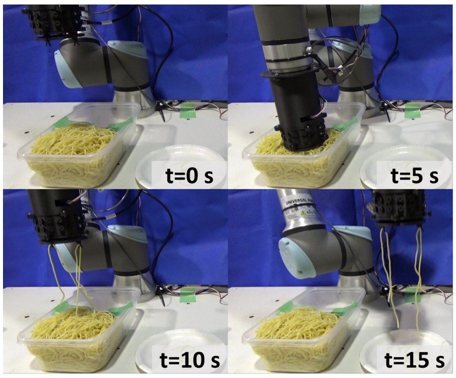


Fig. 5: Grasping experiment

2) Results: First, we compare the average number of grasps as shown in Fig. 6. Error bars in the figure indicate 95% confidence intervals. The Tapered type was 0.61, whereas The Spreading out type was 1.09, showing a slight error from the target value. In Fig. 7, we can compare the percentage of each type of grasp. Black, green, yellow, and red indicate the percentage of trials in which 0, 1, 2, and 3 spaghetti were grasped, respectively. The grasping rate of one spaghetti indicated by green was 41% for the Tapered type and 70% for the Spreading out type, showing that the Spreading out type grasped one spaghetti with higher accuracy.

C. Detailed Finger Design and Comparison Experiment

Using the Spreading out type, which had high gripping accuracy in the previous section, we set two parameters, the maximum opening width w and the gripping surface height h, as shown in Fig. 4(b), and found their optimum values. The definition of the gripping surface height h is shown in Fig. 4. In the experiment, three fingers with different maximum opening widths w, Narrow, Nominal, and Wide, were fabricated as shown in TABLE II, and the grasping accuracy was measured for each of them. Next, in addition to the Nominal finger, we conducted the same experiment using two fingers, Short and Long, with a different gripping surface heights h. In all subsequent experiments, the number of sets of fingers concentrically attached to the end-effector was increased from 2 to 4.

1) Results: First, comparing the fingers with different maximum opening widths w, the average number of Nominal grasped was 1.07, which was the closest to the target value, as shown in Fig. 8(a). On the other hand, as shown in Fig. 8(b), when comparing the percentages of a single spaghetti grasping, Nominal had the highest accuracy at 77%, followed by Narrow at 71%.

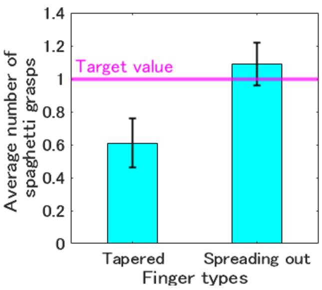


Fig. 6: Average number of grasps for each finger shape

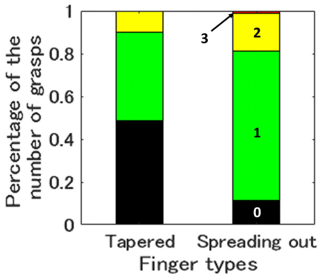


Fig. 7: Percentage of the number of grasps for each finger shape

TABLE II: Finger shapes used in the comparison experiments

	Nominal	Narrow	Wide	Short	Long
w	3.0 mm	2.0 mm	4.0 mm	3.0 mm	3.0 mm
h	4.0 mm	4.0 mm	4.0 mm	2.5 mm	5.5 mm

Next, we compare the results for fingers with different gripping surface heights h. As shown in Fig. 8(c), the average number of fingers grasped was 0.93 for Short, which was the closest to the target value together with Nominal.As shown in Fig. 8(d), the percentage of single grasp was the highest for Short (85%) among all the five shapes. Therefore, it is clear that the optimal shape is the one with the maximum opening width $w = 3.0$ mm, and the gripping surface height $h = 2.5$ mm.

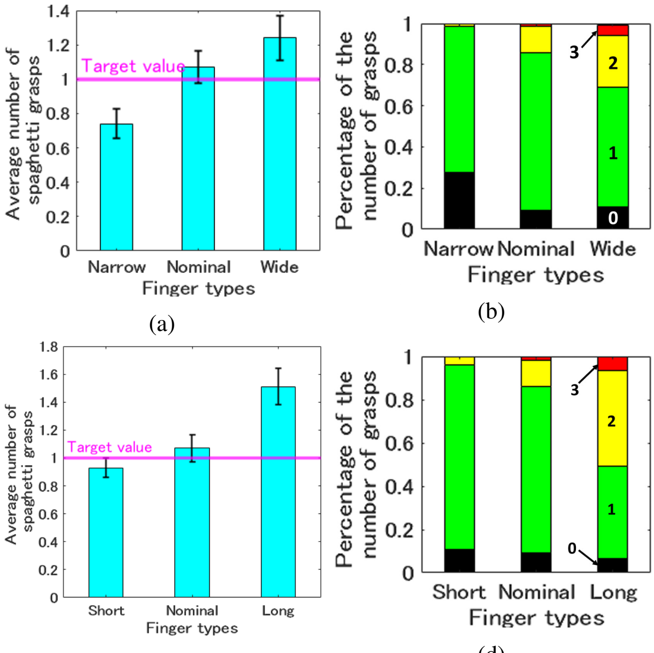
D. Comparison experiment by finger opening/closing speed

Next, as shown in TABLE III, we conducted a comparison experiment by dividing the finger opening and closing speeds into three different levels.

TABLE III: Parameter setting for finger opening/closing speed

	Slow	Middle	Fast
Opening/closing time	3.0 sec	1.0 sec	0.7 sec

1) Results: As shown in Fig. 10, the Slow, Middle, and Fast types were able to grasp only one piece of spaghetti 83%, 79%, and 74% of the time, respectively. From these results, we found that the grasping accuracy did not decrease much even if the opening/closing speed was shortened to about 1 second, and the decrease in grasping accuracy became more significant when the opening/closing speed was shortened to less than 1 second. When this mechanism is used for a practical application, a reduction in cycle time is required. This result suggests a high level of both speed and accuracy can be maintained by reducing the opening/closing speed up to approximately 1 second.



(a) (b) (c) (d)

Fig. 8: Average number of grasps and percentage of grasps in each shape

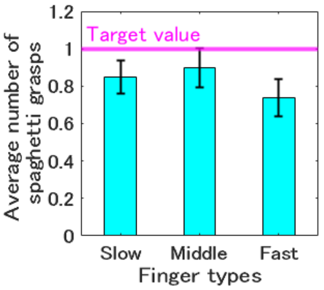


Fig. 9: Average number of grasps at each speed

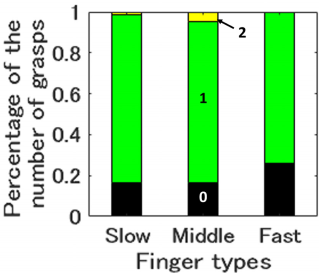


Fig. 10: Percentage of the number of grasps at each speed

E. *Comparison experiment by the rotation speed of vertical axis*

We investigated the influence of the rotational speed of the grasped food on the grasping accuracy. We rotated the entire end-effector or the food tray around the vertical axis to increase the uniform chance of grasping. As shown in TABLE IV, we divided the rotation speed of the vertical axis into three levels and compared the results with those of the static condition. In the Fast and Middle cases, the entire end-effector was rotated by UR5e. In the Turntable case, a turntable was placed under a tray of spaghetti to turn the food.

TABLE IV: Parameter setting of the rotation speed of vertical axis

	Fast	Middle	Turntable	Static
Rotation speed	0.98 rad/s	0.49 rad/s	0.13 rad/s	0 rad/s

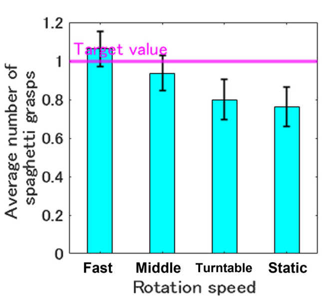


Fig. 11: Average number of grasps at rotation speed

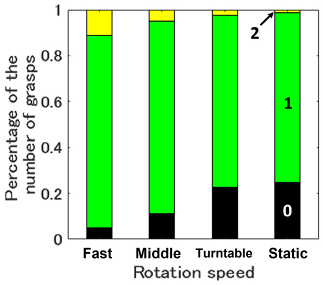


Fig. 12: Percentage of the number of grasps at each rotation speed

1) Results: As shown in Fig. 11, there was a positive correlation between the rotation speed of the vertical axis and the average number of grasped objects. As shown in Fig. 12, the success rate of grasping only one spaghetti was 84% for Fast and Middle. The probability of grasping two or more pieces of spaghetti increased as the rotation speed increased, but the probability of not grasping any piece of spaghetti decreased even more. As a result, the success rate of grasping only one spaghetti increased proportion to the rotational speed.

F. *Grasping experiments with other kinds of noodles*

Based on the experimental results of chapters B, C, D, and E, the grasping accuracy of different foods than spaghetti was determined by experiment. Shirataki, a type of noodle used traditional Japanese food was used in the experiments. The physical properties of shirataki are shown in TABLE V. As in Chapter C, three types of finger shapes, Nominal, Short, and Long, were used in the experiments. For the parameters set in sections D and E of this chapter, we used an opening/closing speed of 3 seconds and a vertical axis rotation speed of 0.98 rad/s, the values that most increased the probability of grasping only one spaghetti.

TABLE V: Physical properties of shirataki

	Weight	Length	Diameter	Coating
Shirataki	2.4 g (ave.)	410 mm (ave.)	2.9 mm	Water

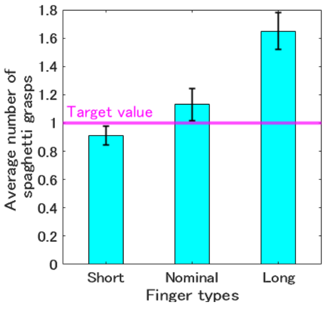


Fig. 13: Average number of grasps for each finger shape

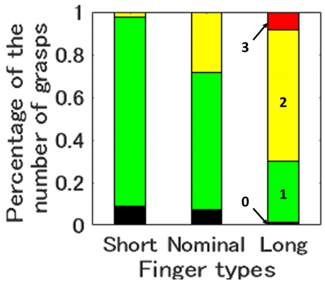


Fig. 14: Percentage of the number of grasps for each finger shape

1) Results: As shown in Fig. 14, as in the spaghetti experiment, the short type had the highest success rate of grasping only one shirataki, with a value of 89%, the highest among all experiments. The diameter of the shirataki was almost the same as that of the spaghetti, but because the surface was not coated with olive oil, the shirataki was less likely to fall out during grasping, and thus extremely high grasping accuracy was obtained.

IV. GRASP DETECTION SYSTEM

In the previous section, we showed that it is possible to grasp only one piece of boiled spaghetti with a success rate of 85%. On the other hand, there is always about 10% of cases of missed grasping due to the viscoelasticity of the spaghetti itself or the decrease in friction caused by the olive oil on the surface, and it is difficult to reduce this probability by only mechanical modification. Therefore, in this section, we propose a method of detecting whether or not the food is successfully grasped by installing a sensor on each finger and adjusting the amount of food with higher precision.

A. Grasp detection using a capacitance sensor

This section proposes a capacitance sensor as a method of grasp detection. Although a method using load cells could be considered a detection method, the capacitance sensor method is adopted because stopping the end-effector for weight measurement may increase cycle time. As shown in Fig. 15, an RC circuit is introduced at each finger, with port A emitting a pulse wave and port B receiving the pulse wave. If there is no capacitance in the circuit, there is no difference in the rise time between ports A and B. On the other hand, if the capacitance is present, a transient phenomenon occurs, and the rise times of ports A and B differ. Assuming that the capacitance of food is C, the resistance between ports, A and B is R, the elapsed time from port A input is t, and the voltages at ports A and B are V_A and V_B, V_B changes with time, as shown in Equation (1). This time the difference is measured, and when it exceeds the threshold value, the spaghetti is judged to be grasped.

$$V_B = V_A(1 - e^{-\frac{1}{CR}t}) \qquad (1)$$

As shown in Fig. 16, we manufactured the measurement circuit by attaching copper foil tape to a resin finger[1]. Since the entire device is made of insulating resin, capacitance other than spaghetti can be neglected.

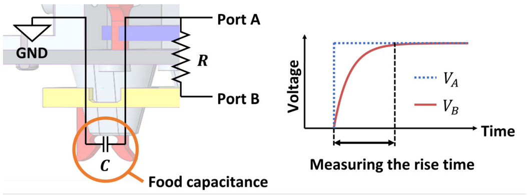


Fig. 15: Principle of capacitance sensor

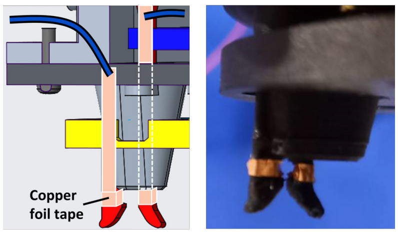


Fig. 16: Installation of the capacitance sensor

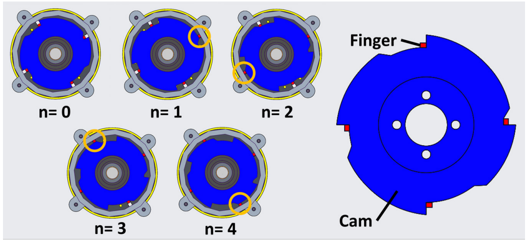


Fig. 17: Cam shape modification and ordering of the opening and closing of the fingers

B. Sequential opening and closing control of fingers

In this end-effector, multiple fingers are opened and closed by pressing them together with a cam in the center. In the previous section, all fingers were opened and closed simultaneously. In this section, we modified the cam shape, as shown in Fig. 17, and controlled the number of fingers to be opened and closed by modulating the rotation angle of the actuator.

C. Automatic control system linked to a scale

As shown in Fig. 18, we constructed an automatic control system for an end-effector in conjunction with a scale for

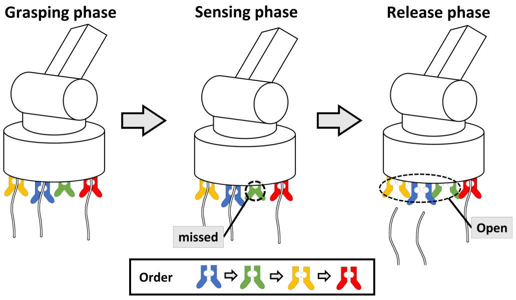


Fig. 18: Sequence of the finger opening and closing

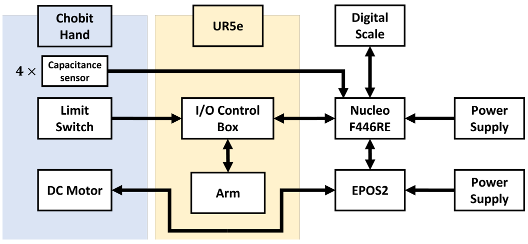


Fig. 19: Block diagram of the system

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[1] Although copper is used for food grasping in this research, it is desirable to construct a circuit using stainless steel for practical application.

weighing spaghetti. The system is divided into three phases. First, in the grasping phase, the system attempts to grasp the spaghetti using all fingers. Next, in the sensing phase, capacitance sensors are used to detect whether each finger is grasping the spaghetti individually. Finally, in the opening phase, some fingers are opened so that the total weight of the spaghetti matches the target weight, and the spaghetti is served. However, since each finger detects whether or not the spaghetti is grasped and cannot measure the weight of the spaghetti being grasped, the average weight of a piece of spaghetti was used. Fig. 19 shows the overall system block diagram. Realtime mass data is acquired from the scale via RS232C communication and the number of spaghetti required are calculated on Microcontroller (ST Micro: Nucleo F446RE). Data from four capacitance sensors are used to detect whether each finger is grasping, and the required actuator rotation angle is sent to a motor driver circuit (Maxon Japan, EPOS2) to rotate the actuator. The UR5e is controlled by Nucleo, which triggers the arm when the motor has stopped.

V. VERIFICATION EXPERIMENT USING SPAGHETTI

A. *Experimental Method*

In the experiment, we used four fingers of the same shape, and a capacitance sensor was attached to each finger. As shown in Fig. 20, Blue, green, yellow, and red markers were attached to each finger on the bottom of the device, and the end-effector released spaghetti in the order of blue, green, yellow, and red. The end-effector grasps the spaghetti packed in a clear plastic container and serves it on a paper dish placed on a scale. The paper plate is previously served with less than 100 g of spaghetti, and the target weight is set to 100 g. If the weight on the scale is less than the target weight after serving, the grasping is repeated until the target weight with a small tolerance. The average weight of each piece of spaghetti is 1.8 g.

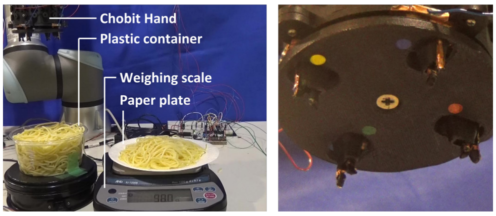

Fig. 20: Equipment used in the experiment

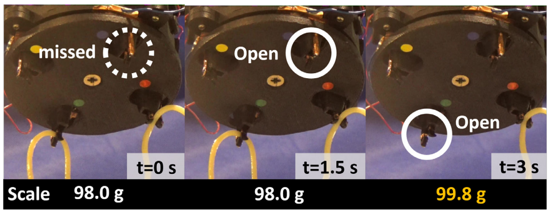

Fig. 21: View of the experiment

B. *Results*

Fig. 21 shows the experiment, taken every 1.5 seconds. At this time, the spaghetti on the paper dish weighs 98 g. The number of spaghetti needed to make up for the error is one. Since the first finger(Fig. 21, blue) fails to grasp the spaghetti, the second finger(Fig. 21, green) is opened, and the spaghetti is placed on the dish; the fourth finger grasps the spaghetti (Fig. 21, red) exceeds the target weight and is returned to the container without being placed on the dish. Thus, we confirmed that the system could adjust the spaghetti serving error with a resolution of approximately 2 g.

VI. CONCLUSIONS

In this study, we proposed a new end-effector that can grasp a small amount of linear food with high accuracy. By installing several tiny fingers and driving a fixed number of fingers according to the error between the target and the measured weight of food, we can precisely adjust the weight of the served food. We showed that the spread fingers are useful for grasping spaghetti, and confirmed that it is possible to grasp a piece of spaghetti with a success rate of up to 85% using multiple parameters.

We also succeeded in developing an end-effector equipped with multiple fingers that can be controlled simultaneously or in sequence. Furthermore, we proposed a capacitance sensor-based a weighing system that can accurately compensate for errors in serving linear-shaped foods, and verified its operation using spaghetti. Attaching fingers of different sizes to different foods makes it possible to grasp a small number of noodles of different diameters with high precision. In the future, we plan to find appropriate finger shapes using foods with different shapes and viscoelastic properties.

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