2026 IEEE/SICE International Symposium on System Integration (SII)
January 11-14, 2026. Cancún, México

Experimental Verification of Vibration-Based Release for a Sticky-Food Handling Gripper

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***Abstract*— In food processing sites, many tasks are still performed manually by workers, and automation through robotics is in high demand. However, research on the release motion of grasped objects remains limited, and the tendency of highly adhesive food materials to stick or remain on grippers has become a major obstacle to automation. In this study, multiple food release methods were compared and examined to ensure the reliable release of grasped food items. Based on the conditions of practically implemented combination weighing machines, particular attention was given to the method of vibrating the gripper fingers. we used a crank mechanism to induce vibrations for experiments involving pork slices laid on metal rods (modeled after the fingers of the Tsummori-Hand), while varying the vibration amplitude, frequency, and angle. The results demonstrated that vibrations exceeding a certain amplitude threshold effectively induced detachment of the adhered material. Furthermore, both higher vibration frequencies and larger vibration angles were found to enhance the release efficiency.**

I. INTRODUCTION

In food processing and production sites, many work processes involving the gripping of food are still performed manually by workers. However, employees often work in physically demanding conditions, such as handling food in chilled rooms to maintain freshness or working with food that is still hot from processing. To address this issue, the replacement of manual operations by robotic hands has been proposed. Previous studies on grippers used for food handling have focused on systems and end-effectors designed to replicate gripping actions [1][2][3]. However, when releasing highly adhesive foods such as raw pork slices or simmered kelp, residues may remain adhered on the gripper. This issue is particularly pronounced in low-temperature environments, where the fat in raw meats increases their adhesiveness, making them more prone to sticking to the gripper. Even if the food is stably gripped and weighed, if a portion remains stuck the actual serving weight may deviate from the target value. Therefore, it is essential to implement a function in food grippers that can reliably release adhered materials.

While there exists an extensive body of research on robotic grasping, studies focusing on the release of grasped objects remain limited. For example, Nojiri et al. developed a gripper utilizing a soft device [4] integrated into the finger sections, capable of switching between blowing and suction, and demonstrated its capability to grasp and release paper boxes. However, when the target object is food, suction-based grasping can allow oils or sauces to enter the air inlet, posing significant hygiene issues. Similarly, Mishima et al. proposed a gripper [5] in which the gripping surface features slit-like openings through which a lubricant is applied, enabling the reliable release of the workpiece without altering the gripping force. Nevertheless, the potential contamination of food by the lubricant renders this approach unsuitable. These limitations highlight the need to investigate methods that can efficiently and reliably release adhesive food items. n this study, the release mechanism is implemented on the ”Tsummori-Hand” [6] (Fig. 1) previously developed by the authors. The Tsummori-Hand serves as the end-effector of the matching weigher (GCW-V, Ishida; Fig. [7]), which is currently used in actual food processing facilities. The purpose of this study is to focus on a method of applying vibrations to its

Fig. 1: Tsummori-Hand©2016 IEEE. Reprinted, with permission from [6]

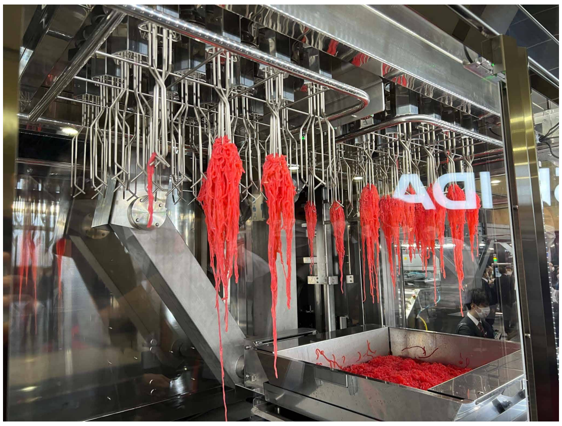

Fig. 2: GCW-V [7]

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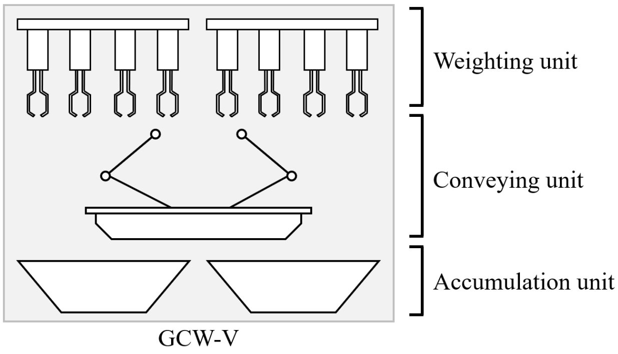

Fig. 3: GCW-V Configuration

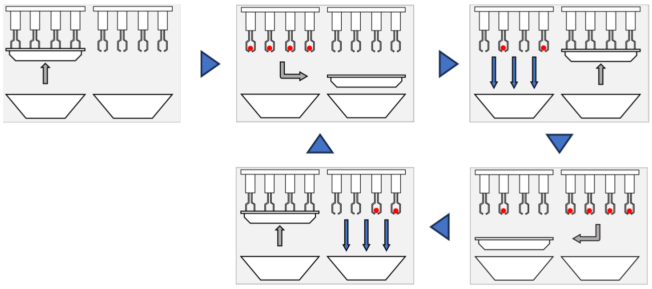

Fig. 4: GCW-V movement

fingers, with the aim of implementing a reliable food release function in the future for the Tsummori-Hand. Using chilled fresh meat as the gripping target, fundamental experiments are conducted to clarify the relationship between amplitude, frequency, vibration direction, and release performance

II. THE MATCHING-WEIGHER (GCW-V)

The matching-weigher (GCW-V, Ishida) is a machine designed to portion and weigh food items accurately. Matching weighing is a method in which the results from multiple hands that have grasped and weighed food are used to rapidly calculate the maximum number of optimal combination patterns that fall within a target weight range. The hands are then sequentially released according to these patterns to achieve the desired target weight. As a result, this system achieves a processing capacity of up to 50 servings per minute, equivalent to the productivity of approximately four human workers. Furthermore, the food-contact parts feature a tool-free detachable structure, and the system itself is washable due to its IP66-equivalent rating, offering excellent cleanability.

A. SYSTEM CONFIGURATION

The GCW-V consists of three main components: weighing unit (gripper array), conveying unit, and accumulation unit (Fig. 3).

1) Weighting unit: performs the gripping, weighing, and releasing of food items in a short time. On the top of the GCW-V, two or more sets of gripper units — each consisting of 16 Tsummori-Hands arranged in four rows of four — are placed side by side. Each hand incorporates a load cell to measure the weight of the gripped food. Based on the obtained measurement values, the system calculates a combination that achieves the target mass and executes sequwntially the release operation.

2) Conveying unit: moves the food trays between the sets of hands. For the mechanism, a two-axis planer parallel-link robot is adopted to achieve both waterproofing and a simple structure. In addition, the remaining quantity in each tray is measured by a laser sensor, and this information is used to control the opening of the hands and the height of the trays.

3) Accumulation unit: Released food items are collected at a single location. Two methods are commonly used for collection: the chute method and the conveyor method, which can be selected according to the type of food and the configuration of the production line.

B. Gripping and Weighing Operation

The operation of the GCW-V is illustrated in Fig. 4. First, a tray filled with food is placed onto the device. Next, the tray is elevated, and the first group of hands grips the food. While one group of hands performs matched weighing and releases the food, the tray is moved to the other group of hands. The same sequence is then repeated with the second group of hands. By alternating between the left and right hand groups, high productivity is achieved.

C. Approach to Adhesion of Sticky Food Materials

The high-functionality configuration and matched weighing of the GCW-V make it a highly efficient automated platform applicable to a wide variety of food products. However, when highly adhesive foods remain on the gripping surfaces, discrepancies arise between the calculated mass and the actual released mass, requiring additional personnel to correct these errors.

The ultimate goal of this study is to propose a release mechanism that focuses on the adhesion problem and to achieve quantitative portioning for a wider variety of foods.

III. INVESTIGATION OF FOOD RELEASE METHODS

To investigate methods for efficiently detaching food adhering to the Tsummori-Hand, multiple potential release techniques were first identified. Among these, the techniques deemed to satisfy the various requirements for a food-handling gripper were selected for further consideration.

In this study, the release methods are considered to be classified into two categories: passive and active methods, as illustrated in Fig. 5. Passive methods include techniques that reduce the adhesion of food to the gripper through surface coatings or modifications of surface morphology. Surface morphology modifications can be broadly categorized into micro-scale treatments, which alter surface properties through features smaller than a few millimeters, and macro-scale treatments, which involve significant changes in surface geometry. On the other hand, active methods encompass approaches such as vibrating the gripping part to detach adhered materials, mechanically brushing them off, blowing them away using pneumatic pressure, or modifying

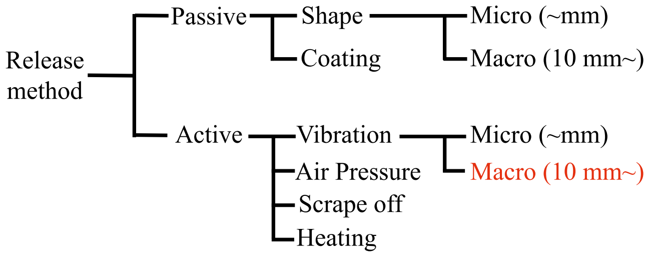

Fig. 5: Various approach to realize the release function

their viscosity through heating. In particular, vibration-based methods can be further subdivided into those that apply micro-scale vibrations to the target and those that induce macro-scale vibrations with large amplitudes. Among these methods, it is necessary to select the approaches that can efficiently release the food.

In selecting the release method, the following constraints are imposed from the perspectives of cost, hygiene, and other considerations in food processing environments.

- To preserve the quality of the food, no gas or liquid jets are applied.
- The performance should remain unaffected even if the surface is covered with food fats or oils.
- To reduce costs, minimized the number of additional actuators.
- Maintain the existing shape of the Tsummori-Hand as much as possible.
- Can be added to the existing Tsummori-Hand.

Among the methods satisfying these conditions, the application of macro-scale vibrations is deemed effective and is consequently adopted in the present study.

IV. VIBRATION-BASED RELEASE

The mechanism by which adhered materials detach due to vibration is considered to occur when the shear force generated between the material and the metal rod exceeds the adhesive force holding the material. Therefore, it is inferred that the greater the acceleration applied along the axis of the metal rod, the larger the resulting shear force, thereby enhancing the detachment efficiency. Since acceleration can be increased by increasing the amplitude and frequency of the vibration, these parameters are regarded as critical factors influencing detachment efficiency. Additionally, depending on the mass and shape of the foods, resonance may occur, leading to the hypothesis that the release performance could be maximized at a specific vibration frequency. To verify this, experiments sweeping the vibration frequency are conducted.

In evaluating the effectiveness of vibration-based release, experiments were conducted using actual raw meat rather than relying on simulation-based analyses. This approach was chosen because accurately modeling objects such as meat, which are both soft and adhesive, is extremely challenging and requires numerous assumptions for model construction. Furthermore, even if modeling were feasible, significant modeling errors could arise due to variations in material properties and contact conditions, making it difficult to fully ensure the validity of the simulation results.

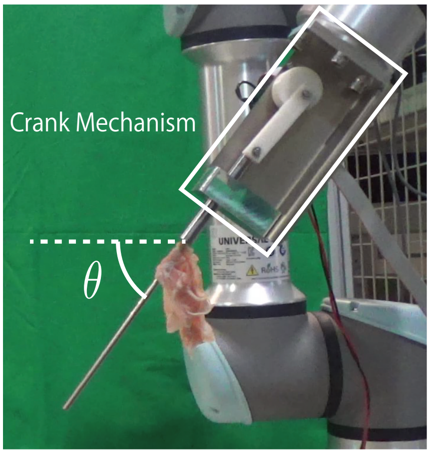

Fig. 6: Experimental equipment to evaluate the effects of vibration

TABLE I: Vibration parameters for experiment with varying amplitude, frequency and rod angle

Parameter	**Value / Range**
Meat Weight (g)	10
Vibration Amplitude (mm)	5, 10, 20
Vibration Angle (deg)	20, 30, 40, 50
Vibration Frequency (Hz)	5, 10, 15 (20, 30, 40)
Vibration Duration (s)	1.0

V. EXPERIMENTAL METHOD

A. *Experimental equipment configuration*

To verify the validity of the vibration mechanism, an experimental apparatus was fabricated, shown in Fig. 6, which allows independent adjustment of both amplitude and frequency. The apparatus is designed such that the metal rod undergoes periodic motion along its axis via a crank mechanism. The vibration amplitude can be varied by adjusting the eccentricity of the crank, while the vibration frequency can be controlled through the rotational speed of the motor. The metal rod, with a diameter of 4 mm (identical to a Tsummori-Hand finger), identical to the finger of the Tsummori-Hand, is attached to the tip of the crank. By mounting this mechanism on a UR5e (Universal Robots), the vibration angle θ can also be freely set.

B. *Experimental Conditions*

The experimental conditions in this study were set to reflect the working environment and constraints of actual food processing lines. To release the food without reducing the current operational efficiency, the time allocated for the release operation was assumed to be approximately one second. Therefore, all experiments were conducted under the premise that the release duration would remain within this constraint.

A single slice of pork was used as the meat sample for the experiments. To minimize variations in shape and thickness,

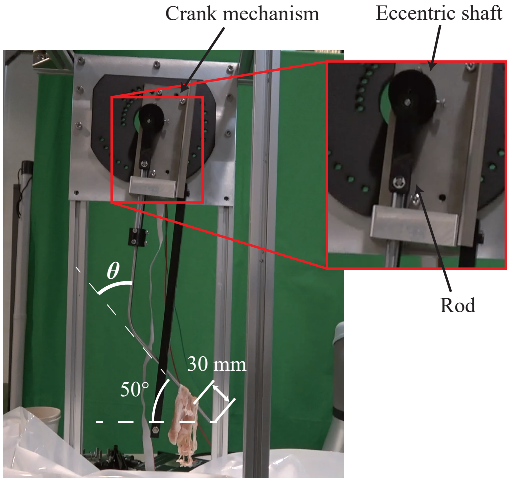

Fig. 7: Experimental equipment to change the direction of vibration

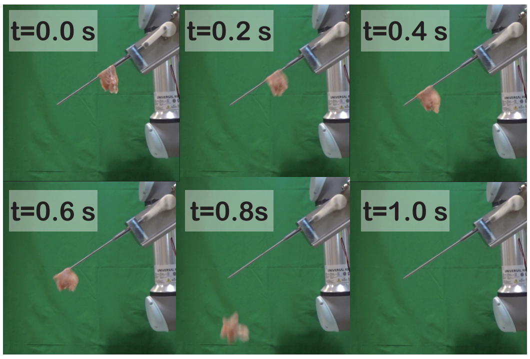

Fig. 8: Vibration-based release experiment

the meat was spread flat to avoid any overlapping portions and attached to the metal rod. In addition, to reproduce the adhesive properties under low-temperature conditions, the meat for each trial was cooled in a portable refrigerator set at 0 °C and removed immediately before the start of the experiment. This temperature setting was chosen to maintain the freshness of the meat while minimizing temperature increases that could affect its adhesiveness. According to the “Guidelines for the Development of Advanced Meat Distribution Structures and Export Expansion Facilities” [8] issued by Japan's Ministry of Agriculture, Forestry and Fisheries, beef carcasses must be cooled to a core temperature of 5 °C or lower within 24 hours. In general, a storage temperature of approximately 0-4 °C is considered desirable for refrigerated meat. Furthermore, a temperature near 0 °C is also recommended in the FAO (Food and Agriculture Organization of the United Nations) [9] Manual on Meat Cold Store Operation and Management as the optimal range for cooling meat without causing surface freezing, indicating consistency with both domestic and international standards.

The primary parameters in the vibration experiments were set as amplitude, frequency, vibration angle, and vibration direction. To evaluate the factors influencing the detachment efficiency of the adhered material, these parameters were varied across experiments.

As shown in Fig. 6, the raw meat was attached 140 mm from the tip of the metal rod mounted on the crank mechanism. Subsequently, vibration was applied along the rod axis for one second, and the movement of the adhered meat was visually evaluated in the three stageds : Fully Realeased, Slight Slip, and No Movement. The vibration amplitude was set at three levels: 5 mm, 10 mm, and 20 mm. For each amplitude, vibrations with three frequencies — 5 Hz, 10 Hz, and 15 Hz — were applied. The inclination angle of the metal rod was varied at 10 deg, 20 deg, 30 deg, 40 deg, and 50 deg, and five repetitions were performed for each condition.Assuming continuous operation of the Tsummori-Hand, the metal rod was not cleaned between trials, and the experiments were conducted with residual fat from the raw meat remaining adhered to its surface. The experimental conditions for these tests are summarized in Table I. In addition, when the amplitude was set to 5 mm, vibrations with higher frequencies of 20 Hz, 30 Hz, and 40 Hz were also tested.

In addition, the tip of the metal rod, representing the gripper finger, was bent to investigate the relationship between the vibration direction, fingertip angle, and detachment. As shown in Fig. 7, the crank mechanism was mounted and fixed on an adjustable platform, attached to a ϕ4 mm metal rod with its tip at a 50 deg inclination w.r.t. to the ground. Vibrations were indicued at angles 0, 45, 60, and 90 deg w.r.t. the rod tip's axial direction.. By changing the direction relative to the rod's axial direction, the relationship between vibration direction and detachment was evaluated. Raw meat was attached 30 mm from the tip along the rod axis, and for each vibration direction, experiments were conducted three times with a vibration amplitude of 20 mm. The movement of the adhered meat was visually evaluated similarly to the previous experiment.

VI. EXPERIMENTAL RESULTS

Table II shows the movement of the raw meat (detachment/sliding or stationary) under varying conditions of amplitude, frequency, and vibration angle. It shows the percentage of trials in which the raw meat was Fully Released (FR), Slight Slip (SS), or No Movement (NM). Fig. 8 depicts the experiment conducted with a vibration amplitude of 20 mm, a frequency of 15 Hz, and an angle of 30 deg.

The experimental results showed that, for a vibration amplitude of 10 mm, no detachment or sliding of the raw meat was observed at frequencies of 5 and 10 Hz. However, when the frequency was increased to 15 Hz and the vibration angle was set to 40 and 50 deg, the meat slid along the metal rod (but did not detach). For a vibration amplitude of 20 mm, detachment or sliding was observed at frequencies of 10 Hz and 15 Hz, regardless of the angle of the metal rod. On the other hand, when the amplitude was 5 mm, the raw meat did not move from its initial position at any frequency. Across the five trials for each condition, no systematic changes in the behavior of the pork slices were observed between the early and later trials. Therefore, the residual adhering material did not affect the experimental results.

TABLE II: Experimental results of food release under different amplitudes, angles, and frequencies.
(FR : Fully Released, SS : Slight Slip, NM : No Movement)

(a) Amplitude = 5 mm

Freq (Hz)	Angle(deg)	FR (%)	SS (%)	NM (%)
5	20	0	0	100
	30	0	0	100
	40	0	0	100
	50	0	0	100
10	20	0	0	100
	30	0	0	100
	40	0	0	100
	50	0	0	100
15	20	0	0	100
	30	0	0	100
	40	0	0	100
	50	0	0	100
20	20	0	0	100
	30	0	0	100
	40	0	0	100
	50	0	0	100
30	20	0	0	100
	30	0	0	100
	40	0	0	100
	50	0	0	100
40	20	0	0	100
	30	0	0	100
	40	0	0	100
	50	0	0	100

(b) Amplitude = 10 mm

Freq (Hz)	Angle(deg)	FR (%)	SS (%)	NM (%)
5	20	0	0	100
	30	0	0	100
	40	0	0	100
	50	0	0	100
10	20	0	0	100
	30	0	100	0
	40	0	100	0
	50	0	100	0
15	20	0	0	100
	30	0	0	100
	40	0	80	20
	50	0	100	0

(c) Amplitude = 20 mm

Freq (Hz)	Angle(deg)	FR (%)	SS (%)	NM (%)
5	20	0	0	100
	30	0	0	100
	40	0	0	100
	50	0	0	100
10	20	0	100	0
	30	0	100	0
	40	0	100	0
	50	0	100	0
15	20	80	20	0
	30	100	0	0
	40	100	0	0
	50	100	0	0

TABLE III: Experimental results of the effects of vibration direction. (FR : Fully Released, SS : Slight Slip, NM : No Movement)

(a) Amplitude = 10 mm

Freq (Hz)	Bending angle(deg)	FR (%)	SS (%)	NM (%)
10	0	0	0	100
	45	0	0	100
	60	0	0	100
	90	0	0	100
15	0	33.3	66.7	0
	45	0	0	100
	60	0	0	100
	90	0	0	100

(b) Amplitude = 20 mm

Freq (Hz)	Bending angle(deg)	FR (%)	SS (%)	NM (%)
10	0	33.3	66.7	0
	45	0	33.3	66.7
	60	0	0	100
	90	0	0	100
15	0	100	0	0
	45	66.7	0	33.3
	60	33.3	0	66.7
	90	0	0	100

Table III shows the behavior of the raw meat when vibration was applied to the bent-tip metal rod.

In the experiments, when the vibration direction was aligned with the axis of the metal rod (0 deg), the raw meat slid along and detached from the rod at both 10 Hz and 15 Hz. However, when the vibration direction was set at 45 deg , the frequency of sliding or detachment decreased compared to the 0 deg case. As the vibration direction approached vertical, at 60 deg and 90 deg, the raw meat was less likely to move from its initial position. Similarlyto the previous experiment, no influence of residual adhering material on the experimental results was observed.

VII. DISCUSSION

A. Investigation of the Effects of Amplitude, Frequency, and Vibration Angle

Based on the results shown in Table II, reliable detachment is achieved when the amplitude exceeds a certain threshold.Furthermore, for a given amplitude, detachment efficiency increased with higher frequencies. These results indicate that the greater the energy of the applied vibration, the more likely the material is to detach. Therefore, within the range of the conducted experiments, the hypothesis that resonance at a specific vibration frequency would facilitate detachment could not be confirmed.

Next, we considered whether the vibration acceleration is not the dominant factor for detachment and organized the experimental results accordingly. On the other hand, since the vibration generated by the crank mechanism is sinusoidal, the acceleration experienced by the metal rod is proportional to both the amplitude and the square of the frequency. Therefore, under the experimental conditions of 5 mm amplitude at 30 Hz and 20 mm amplitude at 15 Hz, the acceleration is the same. However, detachment or sliding of the raw meat was observed at 20 mm amplitude at 15 Hz, whereas no movement was observed at 5 mm amplitude at 30 Hz. This suggests that the axial acceleration of the metal rod has a weak influence on detachment efficiency, and that amplitude is the dominant factor. The strong influence of amplitude on detachment is considered to be due to the flexibility of the raw meat. When the amplitude is small, the vibration is absorbed by deformation of the meat, causing minimal displacement of its center of mass and insufficient shear force between the meat and the metal rod, preventing detachment. In contrast, when the amplitude is sufficiently large, the vibration is not absorbed by the meat's flexibility, leading to substantial fluctuations in the center of mass, which results in detachment.

Furthermore, the results indicate that increasing the tilt angle of the metal rod enhances the detachment effect of the adhered material. This can be attributed to the fact that a larger rod inclination increases the component of the force due to the weight of the raw meat acting in the shear direction between the meat and the rod, making it easier for the shear force induced by vibration to exceed the adhesive force, thus causing sliding. Consequently, when the rod inclination is small, the weight of the meat acts more directly to press the meat against the rod, increasing the adhesive force and making detachment less likely. On the other hand, if the increase in shear force due to a larger rod angle were dominant, changes in the rod angle would be expected to affect detachment efficiency. However, no significant influence of rod angle on the experimental outcomes was observed for a vibration amplitude of 10 mm at 10 Hz, and similarly, 20 mm amplitude at 10 Hz, no notable differences in the frequency of sliding or detachment were observed. Therefore, it was concluded that the inclination angle of the metal rod does not have a dominant effect on the detachment efficiency of adhered material.

B. Investigation of the Effect of Vibration Direction

Based on the results shown in Table III, detachment efficiency was highest when the vibration direction was parallel to the axis of the metal rod, and it decreased as the vibration direction approached vertical. When the vibration direction is parallel to the rod axis, the shear force between the meat and the rod aligns with the vibration direction, facilitating detachment. Conversely, as the vibration direction approaches 90 ° , the force component perpendicular to the shear direction increases, making detachment less likely.

VIII. CONCLUSION

In this study, we investigated a vibration-based approach to address the problem of highly adhesive food materials remaining on the gripping surfaces, which has been a persistent issue in the GCW-V. As an experimental apparatus, a continuous vibration mechanism using a crank system was designed and fabricated to evaluate the releasing performance of adhered materials on the gripper fingers.

In the experiments investigating the effect of vibration on detachment, it was confirmed that vibrations exceeding a certain amplitude were effective in inducing detachment. Furthermore, detachment efficiency was observed to increase with higher frequencies and larger vibration angles.

In future work, the parameters such as amplitude and frequency that most effectively enhance the detachment effect will be identified, and the design of a Tsummori-Hand incorporating these release methods will be pursued. Although this study focused exclusively on sliced pork as the test material, the proposed vibration-based detachment mechanism is considered to be applicable to a wider range of food materials. Therefore, the scope of the experiments will be expanded to include other ingredients such as beef and chicken, in order to further investigate the generalizability of the proposed method and the influence of material dependency.

ACKNOWLEDGMENT

The authors sincerely thank Ishida Co., Ltd. for their cooperation in the conduct of this research.

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