A Customized Multi-Size Egg Tart Carton Packaging Machine

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Abstract. Now the industries must respond proactively to meet rapid changing market demands. A packaging machine adapted to multi-size egg tart carton packaging was designed. The equivalent mechanism of carton folding is to be described the carton panels as links and carton crease lines as joints. Based on the folding procedure of the egg tart carton, there was a sequential motion between all the panels and the crease lines. Due to the diversity of motion trajectories and controllable motion of a coaxial layout 5R mechanism, which was chosen as a cover folding device to fold 2pcs, 3pcs, 4pcs, 6pcs egg trays carton. Moreover, the experimental validation system in a packaging robotic machine was developed to meet the demand of carton customization.

Keywords: Customized Egg Tart Carton, Multi-size, Packaging Machine, 5R mechanism

1   Introduction

The global food packaging is a USD 303.26 billion market which includes paper and cardboard, plastics, metal, glass, and the market demand for food packaging is rapidly growing [1]. In particular, the demand for paper packaging continues to grow, which provides consumers with a green, faster, and safer life services. The paper packaging materials account for more than 40% of the four major packaging materials, which are widely used in food packaging, home appliance packaging, and other fields [2-3].

At present, general food packaging is mainly manual operation in candy, pastries and other food retail industry. Existing food packaging production lines have a single packaging object, poor flexibility, cannot fully adapt to the needs of customization and other issues. In fact, demands for products are changing rapidly, various changes and innovations are proposed to deal with these changes. Therefore, some automated, intelligent and flexible packaging machines have yet to be developed. If there is no reconfigurable machine to join the work, this kind of business is not economically feasible. Further, a smart and reconfigurable machine with robotic fingers is needed in folding packaging which has a manipulator to adapt to various situations to meet customers' demand.

Literature [4] provided an overview of the cardboard packaging and the reconfiguration principles for packaging in the food industry, and motion analysis was the first

standard reconfiguration principle to be considered. The demonstration of this technology is very useful in origami-type cardboard packaging. Literature [5-8] studied the motion model and folding procedure of the carton folding, a new mechanism for the carton was presented and a reconfigurable packaging system for carton was developed. The experimental systems strongly supported the theories. These researches focused on kinematics and motion of carton folding with a aim to produce a multifunctional carton folding machine, and a packaging robot can reduce labor intensity and labor cost.

This paper takes the folding of egg tart cartons in multiple sizes as the research object and designs an automatic folding packaging machine. Egg tart is a pastry food that cannot be squeezed, its outer packaging must give the egg tart enough space to protect it from deformation. The parallel mechanism has good rigidity and strong carrying capacity. As a parallel manipulator, the 2-DOF 5R mechanism has the characteristics of controllable input movement, flexible output movement, and quick response to external functional requirements [9-10]. The folding motion of an egg tarts carton can be equivalent to a model in which the crease lines are used as the axis of rotation on the adjacent surfaces of the carton, and the motion can be equivalent to a rotating pair. In the paper, the folding packaging machine of various sizes egg tart cartons is designed, and the experimental verification is carried out.

This paper is organized as follows: the first part describes the size and the structure of customized egg tart carton and folding process. The next part shows the workflow and design scheme of the packing machine for different carton ranges, and the components of the packaging machine is introduced using folding principles. In the fourth part, the main components of egg tart carton packing machine are introduced, the 5R mechanism with coaxial layout [11-13] as the folding manipulator of cover panel, and a kind of tongue insert packaging robot is designed that can adapt to multi-size of shallow plate carton. In the fifth part, the experimental prototype system is designed, including the control model and experimental prototype. The last part shows the conclusion.

2 Customized Egg Tart Carton and Folding

Customized egg tart carton is usually made of white cardboard sheet, which applies to hold instant foods. Generally, there are diverse size as customers' requirements, which are ranging from 2pcs to 8pcs packing with different sizes. In the paper, the series sizes of egg tart cartons are as follows：
   2pcs Packing: H35×W78×L145mm.
   3pcs Packing: H35×W80×L220mm.
   4pcs Packing: H37×W143×L143mm.
   6pcs Packing: H37×W152×L230mm.

2.1 The structure of customized egg tart carton

Egg tart carton is a typical plate-shaped carton with crease lines, panels and tongue, which is composed of adjacent panels with crease lines folded sequentially. The flat

structure of the egg tart carton is shown in Fig.1. The flat and folded egg tart carton physical figure as shown in Fig.2.
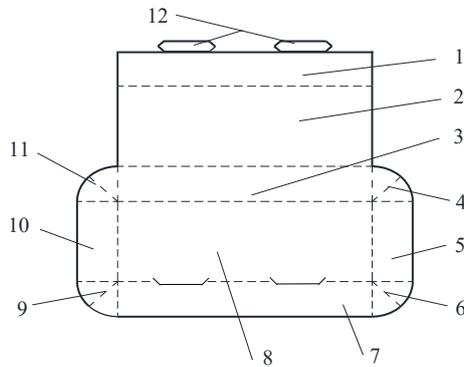

Fig. 1. The flat structure of customized egg tart carton（1. front panel, 2.cover panel, 3.rear panel, 4. right rear flap, 5.right panel, 6.right front flap, 7.front inner panel, 8.base panel, 9.left front flap, 10.left panel, 11.right rear flap, 12.tongue）

In Fig.1, the dotted lines represent crease lines, which can be viewed as the hinge joints of the kinematic mechanism. All panels implement the folding action of the carton along the crease lines. The four flaps fold to drive the adjacent panels to fold in order.

(a)   (b)

Fig. 2. Egg tart carton. (a) flat carton (b) folding carton.

2.2   Folding process

The egg tart carton folding begins with a flat cardboard, which performs crease lines folding, panels closure, tongue insertion and other motions to achieve the carton folding. The folding process of the egg tart carton is to indent crease lines, flaps, folding panels, tongues, and change the relative position between the covers and panels of the egg tart carton.

Fig.3 shows the egg tart carton folding process. Fig.3(a) is the initial flat carton unfolding, Fig.3(b) shows four flaps indentation and folding along the established trajectory of motion, Fig.3(c) shows flaps folded, Fig.3(d) shows the cover folding along the established trajectory of motion, Fig.3(e) shows the front panel folding along the cover crease line, Fig.3(f) shows the tongue folding along the crease into the carton and the carton packaging is completed.
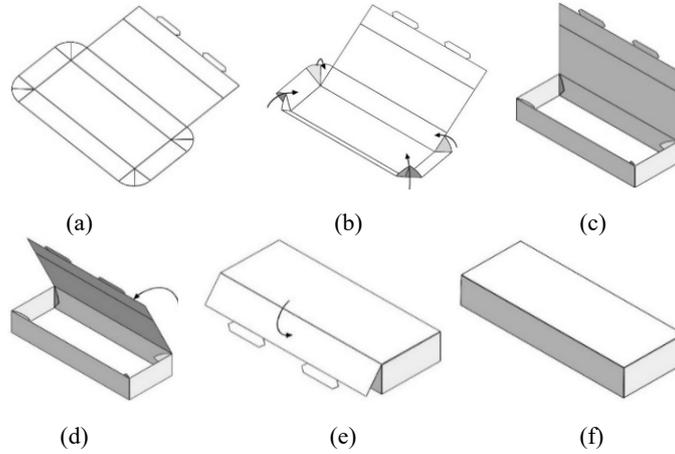
Fig. 3. Folding process of egg tart carton. (a) flat cardboard (b) folding four flaps (c) complete folding flaps(d) folding cover panel, (e) folding front panel (f) folding tongue.

3 Workflow and design scheme of the packing machine

Based on the folding process of egg tart carton, a tray carton packing machine with controllable 5R mechanism was designed to fold the egg tart carton. The workflow of the packaging machine is shown in Fig.4. The whole packaging machine is controlled by the sequential process program, and the position and posture of each assembly module can be adjusted.
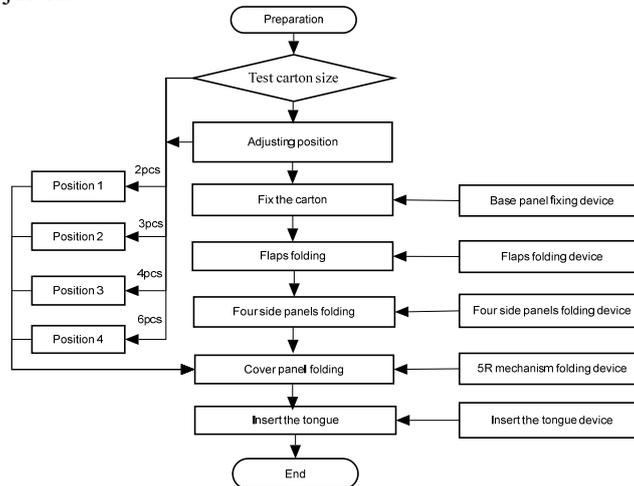

Fig. 4. The workflow of the packaging machine.

First, the carton is fixed to the workbench by suction cups. As the change of egg tart carton size (2pcs, 3pcs, 4pcas, 6pcs), the sensor feedback of adjustment device to select

the correspond working position. At the same time, the four flaps are folded by flaps folding device, which look like fingers, the process as shown in Fig.3(b). And the four side panels folding are folded by the four side panels folding device. So, the rear panel, right panel, front inner panel and left panel are folded, as shown in Fig.3(c).

A coaxial layout 5R mechanism is designed to fold cover panel. According to the position of the carton size, the end output trajectory of 5R mechanism is planned, and the positions of 2pcs, 3pcs, 4pcs and 6pcs egg tart carton with different specifications are adjusted to realize flexible control of the end output track. With the help of the 5R mechanism, the cover panel and front panel are folded, as shown in Fig.3(d) and Fig.3(e).

The packing machine is composed of base support, flap folding, panel folding, adapting and adjusting, cover folding and tongue guiding device. Three-dimensional model of egg tart carton packing machine is shown in Fig.5.
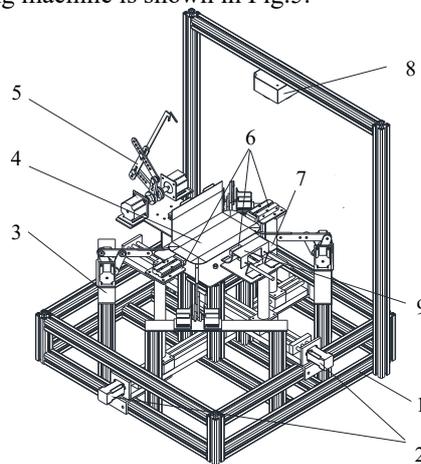

Fig. 5. Three-dimensional model of egg tart carton packing machine. (1. base support device, 2. adjustment device, 3. flaps folding device, 4. carton, 5. cover panel folding device-5R mechanism, 6. four side panels folding device, 7. cover panel folding device, 8. control system, 9. tongue guide device)

4 The main components of egg tart carton packing machine

4.1 Flap folding device

The four-corner flap of the carton rotates the origin with its corner vertex, moving along the arc trajectory, and the carton flaps are realized from flat to fold, as shown in Fig.3(d).

Four carton flaps folding devices with a certain elevation are designed and installed in the four positions of the front left, back left, front right and rear of the adjustment device, as shown in Fig.6. A folding mechanism consists of a U-shaped plate, an mounting plate, a miniature cylinder, a cylinder fixing plate, and a cylinder bend sheet metal.
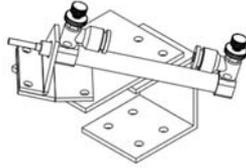
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Fig. 6. Flap folding device.

When the carton is absorbed and secured, the miniature cylinder of the carton flap folding device protrudes and the flaps along the arc trajectory are folded, thus causing the side panel of the carton to rotate and fold along the crease.

4.2 Side panel folding device

The side panel folding motion is equivalent to a motion model in which the side panel of the carton rotates around the crease line, as shown in Fig.3 (c).

The side panel folding device, as shown in Fig.7. It is fixed to the slider of the package adaptation adjustment device and folds the four side panels of the paper tray with the help of the push bar of the four two-bar double-axis cylinders. When the four corners of the carton are folded, the four-position cylinders extend out to fold the side panels, thus the bottom of the carton tray is formed, as shown in Fig.3 (c).
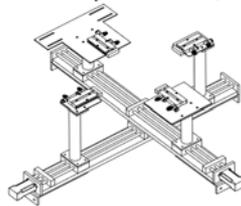

Fig. 7. Side panel folding device

4.3 5R Mechanism Kinematics and cover panel folding

5R Mechanism Kinematics Model. The 5R mechanism with symmetrical structure is shown in Fig.8(a). The linkage AE is the base, the linkage AB and linkage DE are the driving parts, the linkages AB and DE are the same length, and the linkage BC and CD are the same length. Currently, it is a two-degree-of-freedom symmetrical 5R mechanism. According to the rod length conditions, different types of 5R mechanisms can be obtained by adjusting the initial posture of the motor. When the axes of the driving joints A and E coincide collinearly, and the base length is 0, that is, $l_5=0$, it is transformed into a metamorphic 5R mechanism with the driving axes coincident, as shown in Fig.8(b).

Theoretical trajectory of cover panel. The cover panel folding motion includes continuous motion of cover panel, front panel and tongue. Different size cartons have a series of different size of theoretical trajectory. The folding motion of the carton is

regarded as a linkage mechanism of continuous rotation, that is, the crease line is regarded as the revolute pair, and the carton panel is regarded as the linkage, see Fig. 9(a). Linkage *OA* stands for rear panel, linkage *AB* stands for cover panel, linkage *BC* stands for cover panel linkage *CD* stands for tongue.
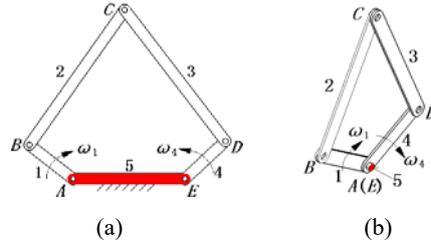

(a) (b)

Fig. 8. The symmetric 5R mechanism. (a) 5R mechanism (b) 5R mechanism of acuated layout with coincident axis.

Every 90° rotation of the linkage mechanism, the center of rotation is transformed once. The center of the rotation circle is O, A_{II}, B_{III}, C_{IV} in order, and the lengths of the rotation radii are OD_I, $A_{II}D_{II}$, $B_{III}D_{III}$, $C_{IV}D_{IV}$ in turn. Finally, it is folded into a carton $OA_{II}B_{III}C_{IV}D_V$. And the theoretical motion trajectory curve $D_ID_{II}D_{III}D_{IV}D_V$ of the end output is formed, which is the blue lines in Fig. 9(b).
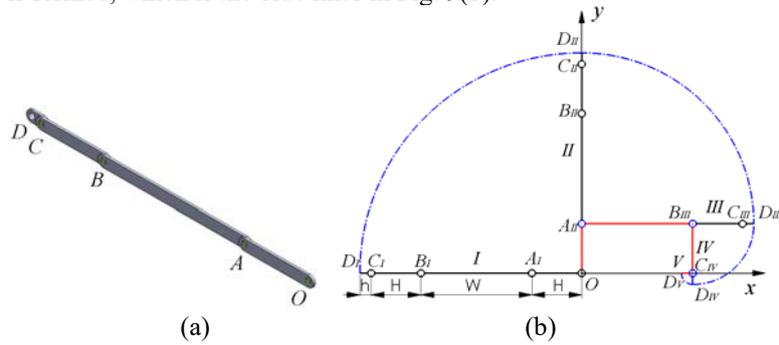

(a) (b)

Fig. 9. Theoretical trajectory of cover panel

The explicit equations of the theoretical motion trajectory are expressed as follows.

$$\text{I－II}: \quad y = \sqrt{(W + 2H + h)^2 - x^2} \qquad x \in [-(W+2H+h), 0] \qquad (1)$$

$$\text{II－III}: \quad y = \sqrt{(W + H + h)^2 - x^2} + H \qquad x \in [0, W+H+h] \qquad (2)$$

$$\text{III－IV}: \quad y = \sqrt{(H + h)^2 - x^2} + H \qquad x \in [W, W+H+h] \qquad (3)$$

$$\text{IV－V}: \quad y = -\sqrt{h^2 - (x - W)^2} \qquad x \in [W-h, W] \qquad (4)$$

8

The cover folding device. A 2-DOF coaxial planar 5R mechanism is selected as the cover folding mechanism, as shown in Fig.10(a). The drive axis of the two motors is collinear. A 60° L-shaped linkage is designed at the end of the 5R mechanism output rod as a finger to realize the motion of inserting tongue, as shown in Fig.10(b).
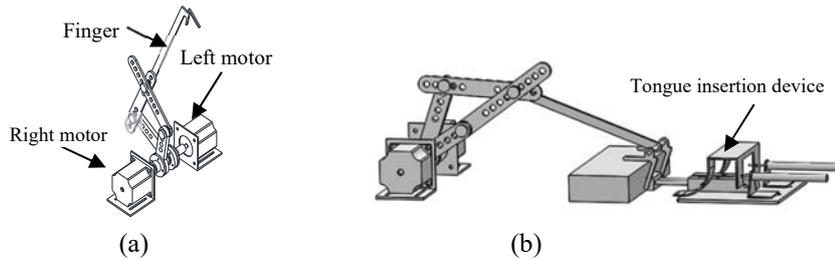

(a)   (b)

Fig. 10. Cover Folding Device. (a)5R Cover folding mechanism, (b) Cover folding and tongue insertion device.

Different angle displacement curves can be entered to achieve the diversity of motion trajectories of the plane 5R mechanism. The rigidity of the 5R mechanism is larger than that of the series mechanism, which can effectively reduce the weight of the end executor and reduce the inertia of the structure.

5   The experimental prototype

5.1   5R mechanism motion control

The process for achieving motion control of the 5R mechanism based on kinematic inverse solution is as follows:

Establish a working coordinate system and define the rotating center of the drive linkage as the origin.

Establish the motion trajectory of the carton folding process and motion simulation. According to the theoretical trajectory curve of cover panel, as shown in Fig.9, the angular velocity of input motors of 5R mechanism are inverse calculated, which through simulation software to track and fit the theoretical trajectory, so the angular velocity curve is obtained, as shown in Fig.11.

The equation of the motion trajectory curve is written to the motor control program, and the speed of input motors are reversed.

5.2   Control system

The control system is composed of pneumatic control system and motor control system. The pneumatic control system is composed of two two-way solenoid valve, two five-way solenoid valve, pressure reducing valve, vacuum generator, filter and air compressor. The motor control system consists of a motion control card, an I/O module, an adjustment driver module, a cover driver module, a flap driver module and a 5R cover

folding mechanism control module with coaxial layout. The control system connection diagram of packaging machine is shown in Fig.12.
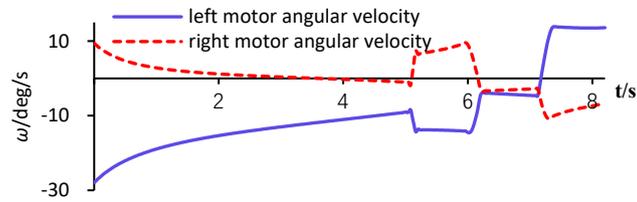

Fig. 11. Inverse solution of motor angular velocity curve of the controllable 5R mechanism

5.3 Experimental prototype machine

By executing control program to adjust the position and posture of 5R mechanism, the packing machine can quickly respond to customized packaging requirements and fold different specifications egg tart cartons.

The effective working space of the prototype is 300 mm×200 mm×50 mm. The carton packing machine can be used to pack 2pcs (145mm×78 mm×35mm), 3pcs (220 mm×80 mm×35mm), 4pcs (143 mm×143mm×37mm), and 6pcs (230 mm×152 mm×37 mm). The experimental prototype of carton packing machine is shown in Fig.13.
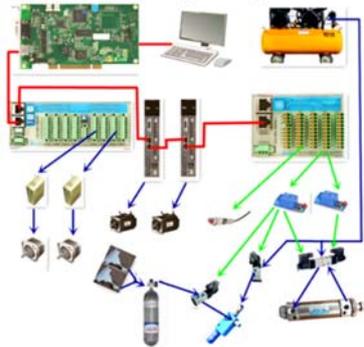

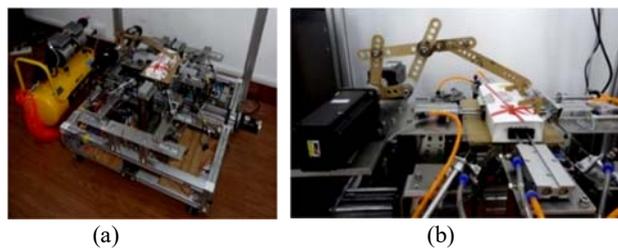**Fig. 12.** control system connection diagram of packaging machine.

(a)   (b)

Fig. 13. The prototype of carton packaging machine. (a)packaging machine, (b)cover folding device.

6   Conclusion

The paper shows a sequential procedure to fold the egg tart carton and a new reconfigurable folding mechanism to be developed. According to the carton folding process, the main component modules of the packaging machine are designed to fold different panels, and the experimental prototype can satisfy the multi-specification tray carton packaging. The coaxial layout of the 5R mechanism is used to control diversified cover motion trajectories. The folding packaging of the multi-standard tray carton has been verified by the experimental prototype, and it is flexible and controllable. Finally, the experimental prototype verifies the efficiency of the design.

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