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Design and experiments of an integrated device for shrimp orientation and decapitation

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Abstract

To realize the automatic orientation and decapitation of shrimp, an integrated device for shrimp orientation and decapitation was designed based on the shape and size characteristics of shrimp, which was mainly composed of oriented rollers, shrimp pushing boards, adaptive clamping claw and knife for the decapitation of shrimp. Three kinds of shrimp of small, medium, and large size were selected. Taking the speed of the shrimp pushing boards, the horizontal speed of the adaptive clamping claw, the rotational speed of oriented rollers and the radius of the oriented rollers as the test factors, and the success rate of the shrimp decapitation as the index, the single factor test and the orthogonal test were carried out to study the effect of each factor on the shrimp decapitation, and then the main parameters of the device were optimized. The results showed that the optimal parameter combinations of the three sizes of shrimp were the speed of shrimp pushing plates of 60mm/s, the horizontal speed of adaptive clamping claw of 70mm/s, the rotational speed of oriented rollers of 60r/min, and the radius of oriented rollers of 20mm. Under the optimal combination of parameters, the device has the highest decapitation success rate and the success rate of shrimp decapitation was 91.5% for small shrimp, 94.6% for medium shrimp, and 92.8% for large shrimp, the decapitation speed was 36pcs/min for small shrimp, 38 pcs/min for medium shrimp, and 37 pcs/min for large shrimp. Therefore, the feasibility of the device design is verified.

Keywords: decapitation; experimental study; integration; orientation; shrimp.

Introduction

Shrimp is rich in animal protein and unsaturated fatty acids, and excellent nutrition can be obtained from shrimp products for consumers in the diet (Liu et al., 2021; Mesa et al., 2021; Wang et al., 2023). The health benefits of consuming shrimp meat create a favorable consumer profile, so worldwide public demand for shrimp is constantly increasing, and there is a growing interest on shrimp processing (Chen et al., 2024; Cheng et al., 2021; N'Souvi et al., 2024). As an important link in shrimp processing, pretreatment processing technology affects the modernization process of aquatic product processing (Wang et al., 2011). Moreover, the separation of the head and tail from shrimp body is also an important process in the pretreatment processing, the excellent separation technology can reduce the waste rate of shrimp meat and increase the income of deep processing of shrimp (Zhang et al., 2017; Nirmal et al., 2020). At present, manual operations are usually used to remove the head and tail of shrimp in China in order to ensure the meat yield of different sizes of shrimp. Considering the high labor-intensive work of removing shrimp heads and tails manually, it should be replaced by automated processing system (Dang et al., 2018; Zhang et al., 2014; Chen et al., 2024). Therefore, the realization of automatic orientation and decapitation of shrimp is the key task of shrimp pretreatment.

At present, there are few research on automatic orientation and decapitation of shrimp at home and abroad. The automation system is widely used in fish processing, and there have been numerous studies using automatic operation for fish-orientation and cutting (Azarmdel et al., 2019; Liu et al., 2022; Omar et al., 2000). The physiological characteristics of shrimp are similar to those of fish, so it can provide a theoretical basis for the automatic orientation and decapitation of shrimp (Okpala et al., 2016). For instance, Dowgiallo et al. (2018) demonstrated the potential influence of the fish-orientation system, which provided close connection with the deheading yield, and the straight-cutting simplifies the precise orientation of the fish in relation to the cutting knives. Booman et al. (2010) designed a fish bone separator machine, which was smaller in size and output but capable of processing hard-boned fish up to 3 kg in weight, and obtained 13% higher processing yield. Bibwe et al. (2013) developed a meat-bone separator for small scale fish, and evaluated Tilapia fish processing in terms of capacity, yield, percentage yield, bone content, color and power consumption. Liu et al. (2017) designed a high-yield head cutting experimental prototype, which performed pretreatment line operations using shearing technology in the field of agricultural products processing combined with body size parameters of bream and grass carp. Chen et al. (2012) reported the mechanical deheading method of typical small marine fish, and the processing methods of toothless disc knife, straight cutting and forward cutting are suitable for lepidotrigla abyssalis, synodus macrops and trachurus japonicus. Zhao et al. (2005) developed an automatic deheading machine for dace, which used a lever-type automatic adjustment mechanism to determine the cutting position of the fish head by contacting the fish body with the roller. Therefore, the use of automated machinery is essential for shrimp processing production, and present study focused on the processing of shrimp using automated processing equipment, which could avoid unnecessary manual waste. An integrated device for shrimp orientation and decapitation was proposed in this study to reduce the loss, which could realize the orientation and decapitation of shrimp at the same time. The objectives of this study were as follows:

(1) Verify the feasibility of the integration of shrimp orientation and decapitation by analyzing the mechanism of shrimp orientation and decapitation.

(2) Analyzed the integrated device for shrimp orientation and decapitation to determine the design parameters of key components.

(3) Obtain the effects of key components on the decapitation rate of the integrated device for shrimp orientation and decapitation under different parameters through prototype tests, and determine the optimal parameter combination.

Materials and Methods

Composition and working principle

The integrated device for orientation and decapitation of shrimp is mainly composed of a feeding port, shrimp blocking boards, receiving tray, oriented rollers, shrimp pushing boards, knife for the decapitation of shrimp on the top, adaptive clamping claw on the bottom, frame, motor and control switches, as shown in Figure 1. The knife for the decapitation of shrimp on the top is installed on the surface of two parallel electric push rods. The electric push rod completes repeated rapid movement in the vertical direction through the slide rail, and the two blades are driven by the electric push rod to achieve closed shearing of the blades. The adaptive clamping claw repeatedly and quickly translates left and right in the horizontal direction through the slide rail, and the electric push rod cooperates with the adaptive clamp to realize the shrimp clamping action. The two oriented rollers are arranged in parallel and the gap is adjustable, which rotates towards each other at the same speed driven by the motor. The shrimp pushing boards are uniformly distributed on the conveyor belt above the oriented rollers and circulate at the same speed in the gap between the two oriented rollers.

Firstly, the head and tail orientation of shrimp is realized by using the structural characteristics of the thickness (the distance between the two sides of the shrimp body) difference between the head and tail of shrimp, and the symmetry between the two sides. The fainted shrimp slide into the gap between the two oriented rollers after reaching the shrimp boards through the feeding port. Shrimp in contact with oriented rollers rotating in opposite directions, maintain a straightened posture (the vertical stretching posture of the shrimp's head up and tail down), and then the shrimp are transported forward by the shrimp pushing boards. Shrimp can be transported to the clamping positions set at the ends of the two rollers in an orderly manner. After observing the arrival of the shrimp, press the switch, adaptive clamping claw accurately picks up the shrimp and horizontally transfers it to the set decapitation position through the slide rail. The upper knife performs transverse shearing on the shrimp transferred from the adaptive clamping claw on the bottom. Since shrimp are soft-bodied organisms, the head and body of shrimp are not completely broken, which affects the head cutting. After the shear is completed, the knives for shrimp head-cutting move vertically upward through the slide rail and form a force in the opposite direction with the clamping force of the adaptive clamping claw on the bottom, which makes the head and body of the shrimp completely broken, and then the head removal of the shrimp is completed.

Mechanism analysis and experimental materials

Penaeus vannamei (Arthropoda, Crustacea, Decapoda, Nematoidea, Penaeidae, and Littoral Penaeus) is selected as the experimental object for measurement, and the measurement method is shown in Figure 2. The fresh shrimp with complete bodies were purchased in a seafood market in Anhui Province. The test materials were classified into three sizes small, medium, and large shrimp by measurement. The shrimp with lengths of 100 mm~110 mm were classified as small shrimp, those with lengths of 110 mm~120 mm were classified as medium shrimp, and those with lengths of 120 mm~130 mm were classified as large shrimp. Fifty shrimp of each size were selected as measurement samples, and the measurement results of shrimp size are shown in Table 1.

The shapes of the shrimp's ventral back and head can be approximately considered as isosceles trapezoid and isosceles triangle respectively, as shown in Figure 3. The thickness of the shrimp gradually increases from the tail to the head, and the connection between the head and the body of the shrimp is the weakest and the thickness of the shrimp is the largest. According to the structural characteristics, when a pair of symmetrical support forces N_1 and N_2 are applied to the waist at the top of the center of gravity, the shrimp reaches the state of force balance.
Cylindrical oriented rollers made of polyester are used as support and working parts and the surface is smooth and hard surfaces. The hyperboloid space formed between the two oriented rollers can adapt to the differences in the shape and size of the shrimp body, and the orientation and squeeze of the shrimp can be completed without causing damage to the shrimp body. The connection between the shrimp's head and body is relaxed after being squeezed, and the shrimp in a straightened posture can be pushed forward smoothly by the shrimp pushing boards. The shrimp body is then clamped by the adaptive clamping claw on the bottom and transferred horizontally to the set decapitation position.
The weakest point of the shrimp body is located at the horizontal line between the center of the two oriented rollers, namely O_1O_2, and the knife for the decapitation of shrimp on the top is also parallel to O_1O_2. The weakest part of the shrimp body is cut by a knife for the decapitation of shrimp on the top and the shrimp initially is broken at the weakest part. After the shearing is completed, the shrimp's head is pulled upward by the closed blades. Due to the clamping of the adaptive clamping claw on the bottom, a reverse force is formed between the shrimp's head and body. The connection between the shrimp's head and body is completely broken, and then the shrimp's head is completely cut. Figure 4 shows the orientation and decapitation process of the shrimp.

Analysis and design of key components

Oriented rollers

Oriented rollers are the main working parts for the orientation of the heads and tails of shrimp, and the radius of the oriented rollers is the key to the success of the shrimp decapitation. Figure 5 (r in the figure represents the radius of the oriented rollers and d represents the distance between the bottom of the two shrimp blocking boards) shows the axial structure of the oriented rollers and shrimp blocking boards.

The vertical distance h between the end of the shrimp blocking boards and the oriented rollers is an important parameter to prevent the shrimp from jumping out of the gap due to friction after sliding into the gap between the oriented rollers. The gap l between the oriented rollers is the key to the success of orientation after falling into the oriented rollers. Therefore, the design parameters of the oriented rollers should be satisfied:

$$\begin{cases} d = 2(r - r \cdot \sin\alpha) + l > h_{max} \\ h_{min} < h < h_{max} \\ h_1 < l < h_2 \end{cases} \tag{1}$$

Where:
h_{max}——Maximum thickness of shrimp, mm
h_{min}——Minimum thickness of shrimp, mm
h_1——Thickness of the shrimp head, mm

h_1——The thickness at the center of gravity, mm

the following formula can be obtained:

$$r > \frac{h_{max} - l}{2(1 - \sin \alpha)} \tag{2}$$

Through experimental measurement, the shrimp slid down the smooth polyester board at a constant speed, the angle between the board and the horizontal plane is the friction angle α ,as shown in Figure 6. The friction angle α of shrimp on the smooth surface of oriented rollers is 38.2°. According to the measurement results in Table 1, the radius of the oriented rollers is larger than 10.3 mm.

As shown in formula 2, when l is constant, r is proportional to d. The larger d is, the easier it is for the shrimp to fall into the gap between the oriented rollers to complete the orientation. Therefore, an appropriate increase in the radius of the oriented rollers is beneficial to orientation shrimp. Since the shrimp's head and tail are oriented, the shrimp body needs to be clamped by the lower adaptive clamping claw from the bottom of the oriented rollers to the decapitation position. Therefore, the tail of the oriented shrimp body should be lower than the bottom of the oriented rollers, and the shrimp body with a straightened posture can be picked up, that is, the radius of the oriented rollers is less than 35.2 mm.

Shrimp pushing boards

To realize the orderly transportation of shrimp in the gap between the oriented rollers at a uniform speed, the upper end of the shrimp pushing boards needs to adapt to the V-shaped contour structure formed by the shrimp blocking boards and oriented rollers and the width of the lower end of the shrimp pushing boards must be smaller than the gap between the oriented rollers. To facilitate the shrimp sliding into the oriented rollers, the distance j between adjacent shrimp pushing boards should be greater than the length of the shrimp's head and tail. As shown in Table 1, the distance j between adjacent shrimp pushing boards is larger than the shrimp length, so the distance from j has to be greater than 130 mm. The number of shrimp pushing boards is designed to be ten, as shown in Figure 7.

To make the shrimp be clamped smoothly to the decapitation position at a straightened posture by the adaptive clamping claw on the bottom, so the time t_2 for the shrimp pushing boards moving to the push position needs to be longer than the time t_1 for the shrimp sliding from the feeding port to the gap between the oriented rollers. The shrimp pushing boards are satisfied:

$$\begin{cases} mgS_1 \sin \delta - f'S_1 = \frac{1}{2} mv_1^2 \\ f' = umg\cos\delta \\ t_1 = \frac{2S_1}{v_1} \\ t_2 = \frac{J - S_2}{v_2} \\ t_1 < t_2 \end{cases} \tag{3}$$

Where:

m——quality of shrimp, kg

v_1——the speed at which the shrimp slides down to the gap of the oriented rollers, m/s

v_2—— speed of shrimp pushing boards, m/s

S_1—— the distance the shrimp slides down through, m
S_2——length of the shrimp pushing boards, m
f'—— friction of shrimp blocking boards on shrimp, N
u——friction factor between shrimp blocking boards and shrimp
g——gravitational acceleration, m/s^2
δ——surface inclination angle of shrimp blocking boards, 60°

Combined with formula (3), it can be obtained that the speed of the shrimp pushing boards v_2 is less than 98.5 mm/s. Reducing the speed of the shrimp pushing boards properly can ensure that the shrimp is orderly transported to the location of the decapitation to achieve the decapitation of the shrimp.

Knife on the top and adaptive clamping claw on the bottom

To ensure that the shrimp is transferred to the decapitation position in the gap between oriented rolls and complete the decapitation, the adaptive clamping claw on the bottom is selected to cooperate with the knives for shrimp decapitation on the top. As shown in Figure 8, the upper part is equipped with a pair of parallel blades. When the blades are open, the gap between the blades is greater than h_{max}. When the two blades are closed, the cutting of the shrimp is completed. With the blades moving vertically, the head and body of the shrimp are then separated.

Images of shrimp in the current state were taken using an HD camera and imported into MATLAB software. Then, the image is processed by grayscale, and the edge contour of shrimp is obtained by Robert operator. The coordinate points of the edge contour line on one side below the head of the shrimp body were obtained by Digitizer in the Origin software, as shown in the Figure 9 a-c. Finally, the coordinate points are drawn into a scatter plot and fitted to obtain the contour equation of the shrimp body. Taking the bottom center of the adaptive clamping claw as the origin, a plane rectangular coordinate system is established, as shown in Figure 9d. The curve in the coordinate system is the contour of the clamping surface at the maximum angle of the adaptive clamping claw. According to the fitted curve from section 5 to the tail of the shrimp, the designed comprehensive clamping curve equation is as follows:

$$f(x) = \begin{cases} 5.217x - 0.233, & 2.1 \le x < 2.9 \\ 0.825x + 10.65, & 2.9 \le x < 3.7 \\ 1.45x + 5.8, & 3.7 \le x < 6.3 \\ 0.15x^2 - 0.6x + 16.3, & 6.3 \le x \le 11.44 \end{cases} \quad (4)$$

Section a_0b_0 is the profile of the clamping surface for clamping the tail of the shrimp, b_0c_0 is the transition line, section c_0d_0 is the profile of the clamping surface that clamps the shrimp body, d_0e_0 is the support curve of the shrimp body.

As shown in Figure 9e, the four clamping surfaces are made of flexible materials to prevent shrimp from being damaged by squeezing, and the clamping surfaces from top to bottom in sequence are a support surface, an upper clamping surface, a transition surface, and a lower clamping surface. The lower clamping surface is flat and the other surfaces are curved. Three rows of conical protrusions are evenly distributed on the surface of the upper clamping surface.

The tail is mainly clamped by the lower clamping surfaces, while the shrimp body is mainly clamped by the upper clamping surfaces. The shrimp is supported by the transition surfaces at the connection between the upper and lower clamping surfaces. The supporting surfaces are mainly used to provide a certain support force to the side of the shrimp, which can prevent the shrimp from shaking around and improve the clamping stability. According to the results of the shrimp extrusion tests, the maximum load that the shrimp can bear without breakage is 24N, as shown in Figure 10. Therefore, the holding force of the adaptive clamping claw with an integrated servo system is selected 24N.

The distance from the position of the adaptive clamping claw to the position of the decapitation is set as S_3, and the speed of the adaptive clamping claw is set as v_3, speed of shrimp pushing boards is v_2. The adaptive clamping claw clamps the shrimp to the position of decapitation and then returns to its original position. To ensure that each shrimp can be clamped, it should be satisfied that $\frac{j}{v_2} > \frac{2S_3}{v_3}$, so 37.04mm/s $< v_3 <$ 88.9mm/s.

Results and Discussion

The decapitation experiment of shrimp

The test equipment is an integrated device for the orientation and decapitation of shrimp, as shown in Figure 11. Other instruments include vernier calipers (accuracy 0.1 mm) and electronic scales (accuracy 0.1 g).

The main evaluation indexes of the device are the success rate of shrimp decapitation and the speed at which the shrimp is decapitated. In addition, the complete fracture of the head and the body of the shrimp without adhesion was considered as the success of decapitation. The calculation formulas of the decapitation rate W and the decapitation speed V_e are respectively:

$$V_e = \frac{W_1}{T} \quad (5)$$

$$W = \frac{W_1}{W_2} \times 100\% \quad (6)$$

where T in the formula is the working time, min, W_1 is the number of shrimp whose heads are successfully cut in each test; W_2 is the number of shrimp samples in each test.

A group of 40 shrimp were randomly selected from the selected shrimp samples. To reduce the test error, the test was repeated 3 times, and the average of the test results of the 3 groups was taken. In the whole test process, the feeding speed of the shrimp was 40 pcs/min, the cutting speed of the knife and the closing and clamping speed of the clamp were 30 mm/s, and the rising and falling speed of the knife after the cutting was completed were 36 mm/s. The speed of oriented rollers, the radius of oriented rollers, the speed of shrimp pushing boards, and the horizontal speed of adaptive clamping claw were taken as the test factors, the decapitation rate was taken as the test index, and the decapitation speed was taken as the reference index. Three kinds of shrimp with small size, medium size, and large sizes were selected as the test objects, and a single-factor test was carried out by selecting suitable gaps of oriented rollers for different types of shrimp.

Effect of the radius of oriented rollers on shrimp decapitation

The rotational speed of oriented rollers was set to 60 r/min, the speed of shrimp pushing boards was set to 60mm/s, and the horizontal speed of the adaptive clamping claw to 70 mm/s. The radius of oriented rollers ranged from 10 mm to 30 mm to explore the impact of the radius of oriented rollers on the decapitation rate and decapitation speed. The results are shown in Figure 12.

The trend of the line graphs corresponding to the three sizes of shrimp is roughly similar. With the increase of the radius of the oriented rollers, the decapitation rate increases first and then decreases. When the radius of oriented rollers is too small, the force on the shrimp in the oriented rollers is small, which leads to the shrimp not easily maintaining a straightened posture and the head of the shrimp cannot be cut in the subsequent process. When the radius of the oriented rollers is too large, the shrimp in the straightened posture is blocked by the oriented rollers, which makes it difficult for the adaptive clamp claw to pick up the shrimp in the straightening posture accurately, so the decapitation rate is reduced. The decapitation speed of shrimp is almost unaffected by the radius of the oriented rolls at 15 mm~25 mm. Therefore, the optimal horizontal range corresponding to the radius of the oriented rollers is 15 mm~25 mm.

Effect of oriented rollers' rotational speed on shrimp decapitation

The radius of the oriented rollers was set to 20mm, the speed of shrimp pushing boards was set to 60 mm/s, and the horizontal speed of the adaptive clamping claw was set to 70 mm/s were used as test subjects, respectively. The oriented rollers' rotational speed was set from 20 r/min to 8 0r/min at a total of 8 levels to explore the effect of the rotational speed of oriented rollers on the decapitation rate and decapitation speed, as shown in Figure 13.

The three polylines have a similar trend. With the increase of the rotational speed of oriented rollers, the decapitation rate firstly gradually increases and then slightly decreases. The decapitation rate is high when the rotational speed of oriented rollers is 40 r/min ~70 r/min. However, when the rotational speed exceeds 60 r/min, the greater the speed, the greater the friction of the shrimp, the shrimp will jump and can not be oriented, thus affecting the decapitation rate and decapitation speed. The optimal range of the rotational speed of oriented rollers is determined to be 40 r/min ~60 r/min.

Effect of pushing board speed on shrimp decapitation

The rotational speed of oriented rollers was set to 60r⁄min, the horizontal speed of the adaptive clamping claw was set to 70mm⁄s, and the radius of oriented rollers was set to 20 mm. The speed of shrimp pushing boards was changed to explore the impact of the speed of shrimp pushing boards on the decapitation rate and decapitation speed. The results are shown in Figure 14.

With the increase in speed of the shrimp pushing boards the decapitation rate shows a trend of decline on the whole. When the speed of the shrimp boards exceeds 80 mm/s, the decapitation rate is significantly reduced and the decapitation speed is also significantly reduced. The shrimp is contacted and then exerted a thrust by the shrimp pushing boards before it has formed a straightened posture. At this time, the shrimp continued to be in an unstraightened posture under the horizontal thrust, failing shrimp decapitation. The faster the speed of the shrimp pushing boards, the less time is left for the shrimp to be oriented, and the more easily the process of shrimp decapitation can be affected. Combined with the speed at which the shrimp is decapitated, the optimal range of the speed of the shrimp pushing boards is 50 mm/s~70 mm/s.

Effect of adaptive clamping claw horizontal speed on shrimp decapitation

The rotational speed of oriented rollers was set as 60 r⁄min, the radius of oriented rollers was set as 20mm, the speed of shrimp pushing boards was set as 60 mm/s, and the horizontal speed of the adaptive clamping claw was gradually increased. The horizontal speed of the adaptive clamping claw was gradually increased to explore the effect of the horizontal speed of the adaptive clamping claw on the decapitation rate and decapitation speed. The results are shown in Figure 15.

The trends of the three polylines are similar. The decapitation rate increases first and then tends to be stable. When the horizontal speed of the adaptive clamping claw is too slow, some shrimp fail to be picked up in time, thus forming a pile, which results in the inability of the heads of shrimp to be removed. When the speed is too fast, the shrimp bodies slip off the adaptive clamping claw, which affects the shrimp's decapitation. According to the comprehensive analysis of the decapitation rate and decapitation speed, the optimal range of horizontal speed of the adaptive clamping claw is determined to be 50 mm/s ~70 mm/s.

Orthogonal test

To explore the influence degree of each factor on shrimp decapitation and determine the optimal horizontal combination, orthogonal tests were carried out based on the results of the single-factor test. Taking the speed of the shrimp pushing boards, the horizontal speed of adaptive clamp claw, the rotational speed of oriented rollers and the radius of oriented rollers as the test factors, and the decapitation rate as the test index, the orthogonal tests of small shrimp, medium shrimp, and large shrimp, were carried out, respectively. The factor levels are shown in Table 2, and the orthogonal table $L_{27}(3^4)$ is used for the test.

The orthogonal test results of shrimp decapitation are shown in Table 3 and Table 4 in which A, B, C, and D represent the speed of shrimp pushing boards, the horizontal speed of adaptive clamping claw, the rotation speed of oriented rollers, and the radius of the oriented rollers, respectively.

The site for the shrimp decapitation test is shown in Figure 16. According to the magnitude of the range, it can be judged that the primary and secondary orders of the factors affecting the decapitation rate of small shrimp and medium shrimp are A, B, C, D. The primary and secondary orders of the factors affecting the decapitation rate of large shrimp are C, B, A, D. The factors affecting the decapitation speed of the three types of shrimp are consistent, and they are A, B ,C , D.

Both the optimal combination of the decapitation rate and the decapitation speed for all three sizes of shrimp are $A_2B_3C_3D_2$, that is, the speed of shrimp pushing boards is taken as 60 mm⁄s, the horizontal speed of the adaptive clamping claw is taken as 70mm/s, the rotational speed of oriented rollers is taken as 60 r⁄min, and the radius of oriented rollers is taken as 20 mm. Under the combination of these parameters, the test device works best. Taking the average of the three groups corresponding to $A_2B_3C_3D_2$, the results showed that the decapitation rate was 91.5% for small shrimp, 94.6% for medium shrimp, and 92.8% for large shrimp, the decapitation speed was 36pcs/min for small shrimp, 38 pcs/min for medium shrimp, and 37 pcs/min for large shrimp. The shrimp heads were completely cut in the test, in which the head and body of the shrimp were completely broken, and the shrimp decapitation effect was the best.

Conclusions

Aiming at the problem that shrimp need artificial orientation and then decapitation, an integrated orientation and decapitation device for shrimp was proposed. The integrated device for shrimp orientation and decapitation is mainly composed of oriented rollers, shrimp pushing boards, adaptive clamping claw, and knife for the decapitation of shrimp to realize orientation, transportation, clamping, and decapitation of shrimp. Three sizes of *Penaeus vannamei* were selected for the single factor test and orthogonal test, respectively. The following conclusions were obtained:

(1) According to the theoretical analysis and the dimension of shrimp, the orientation test of shrimp was carried out. The test shows that the shrimp orientation can be achieved by smooth parallel rotation of the opposite roller, and the joint of the head and the body of the shrimp are located at the horizontal line of the center of the side of the two rollers.

(2) Through the relevant calculation, the parameter range of the key components is determined. The value of the radius of oriented rollers ranges from 10.3mm to 35.2mm, the speed of shrimp pushing boards is less than 98.5mm/s, the clamping force of the adaptive clamping claw is 24N, the horizontal speed of adaptive clamping claw from 37.04mm/s to 88.9mm/s.

(3) Through an orthogonal test, the optimal parameter combination is determined. The results that when the speed of shrimp pushing boards was 60mm/s, the horizontal speed of the adaptive clamping claw was 70mm/s, the rotational speed of oriented rollers was 60r/min, and the radius of oriented rollers was 20mm, the decapitation rate was 91.5% for small shrimp, 94.6% for medium shrimp and 92.8% for large shrimp, the decapitation speed was 36pcs/min for small shrimp, 38 pcs/min for medium shrimp, and 37 pcs/min for large shrimp.

(4) The device can not only meet the decapitation of shrimp in the paper but also meet the decapitation of other soft-bodied types of shrimp. However, the device for shrimp decapitation is limited by the size of the shrimp, different sizes of shrimp need to correspond to the gap to maximize the efficiency of the work, it can be considered to improve the device or the addition of a grading device, to achieve different sizes of shrimp decapitation at the same time. To improve the structure of the device can not only be decapitated shrimp, but even the body structure of similar soft-bodied organisms for cutting, such as fish.

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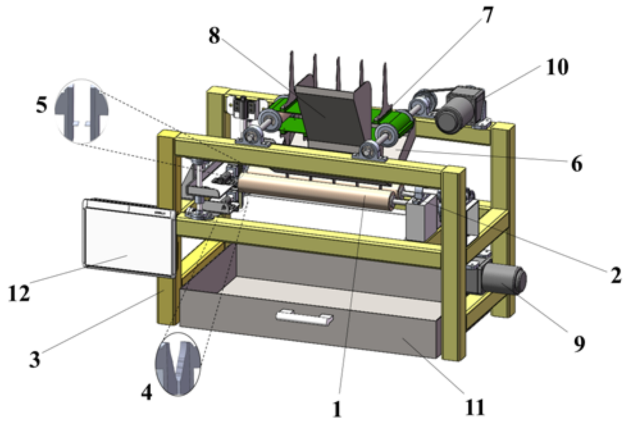

Figure 1. Structure diagram of an integrated device for shrimp orientation and decapitation. 1). Left oriented roller; 2). Right oriented roller; 3). Frame; 4). Adaptive clamping claw on the bottom; 5). Knife for decapitation of shrimp on the top; 6). Shrimp blocking boards; 7). Shrimp pushing boards; 8). Feeding port; 9). First motor; 10). Second motor; 11). Receiving tray; 12). Control switches.

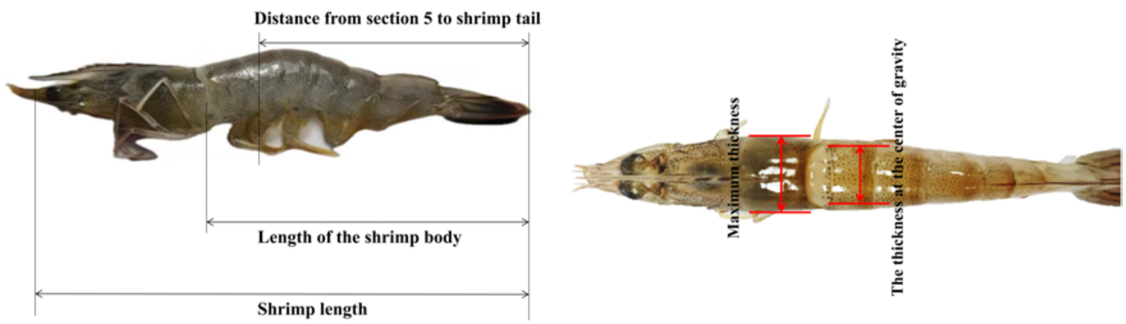

Figure 2. Methods of measuring shrimp size.

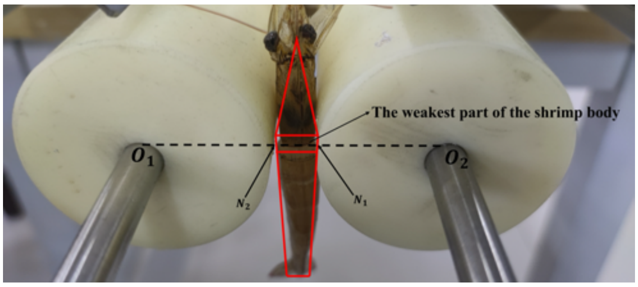

Figure 3. Orientation test of shrimp.

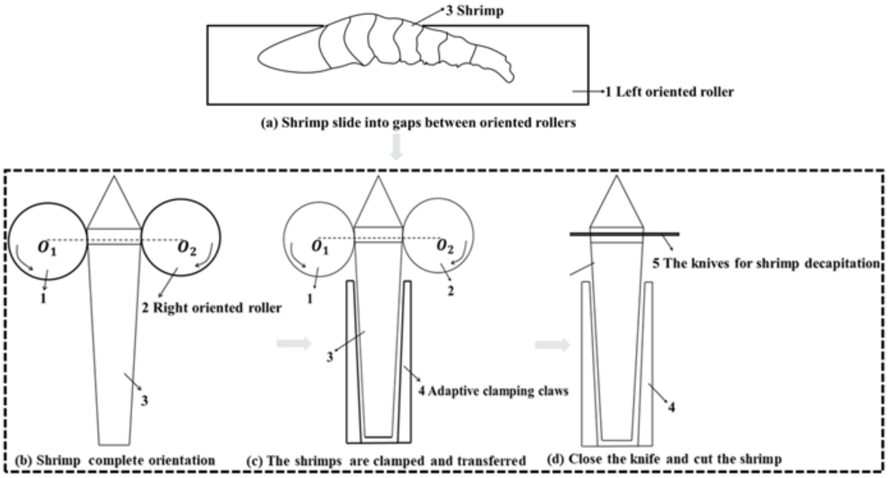

Figure 4. Simplified diagram of the shrimp orientation and decapitation process.

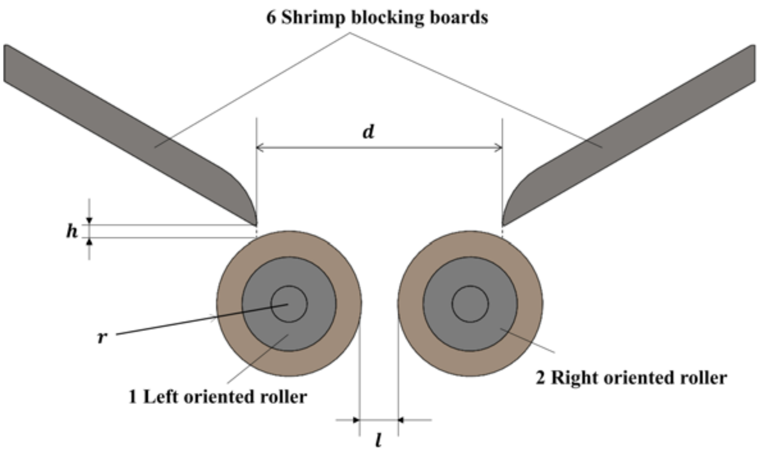

Figure 5. The axial structure of the oriented rollers and shrimp blocking boards.

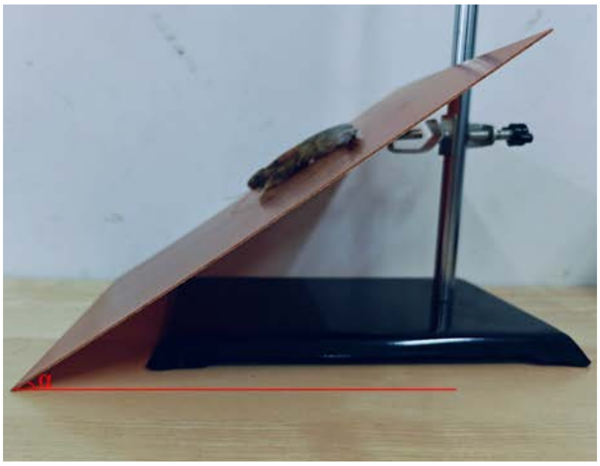

Figure 6. Friction angle test.

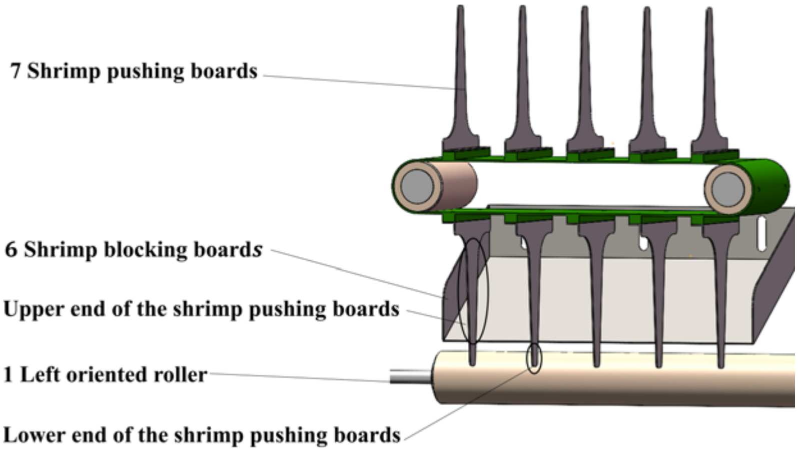

Figure 7. The structure of the shrimp pushing boards.

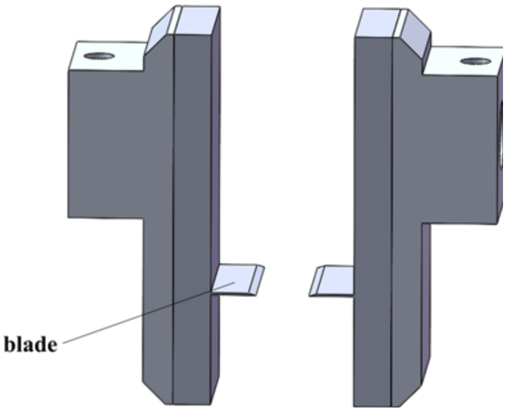

Figure 8. The structure of the knife used to decapitate the shrimp.

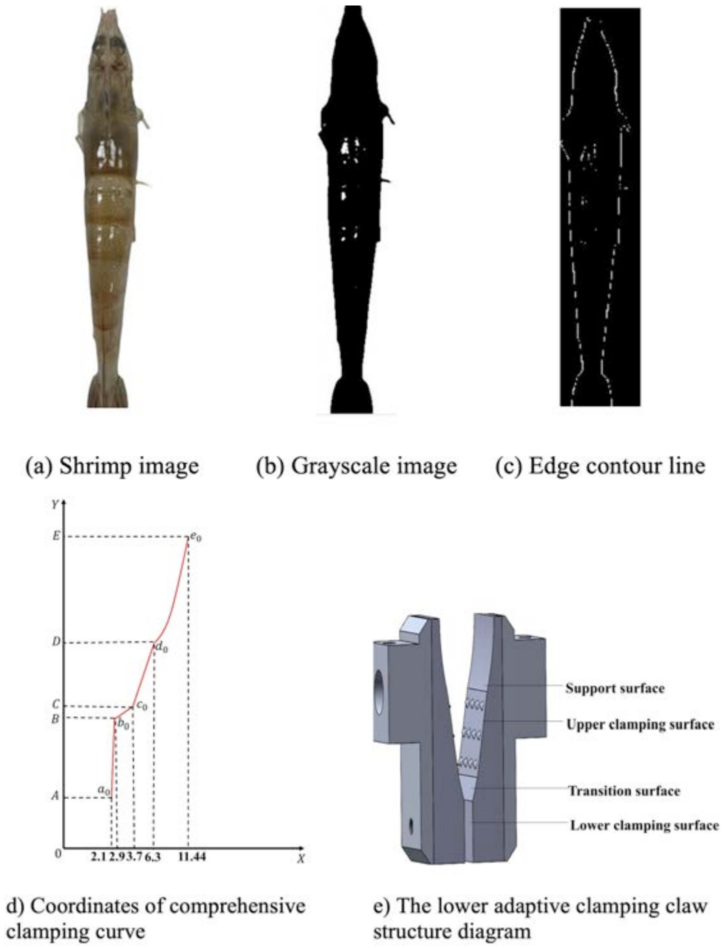

Figure 9. The profile design of the surface of the adaptive clamping claw.

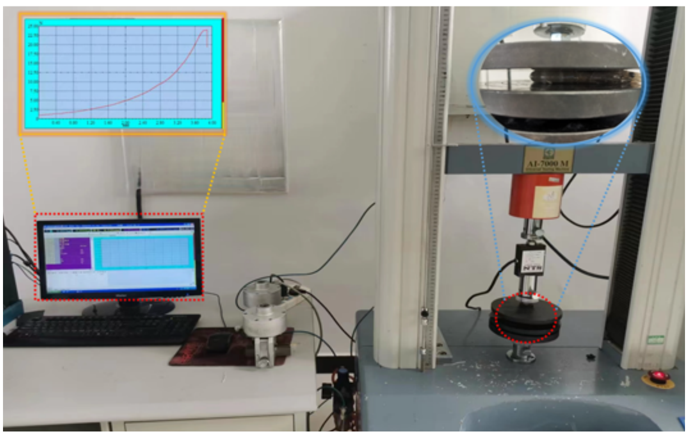

Figure 10. Squeeze test of shrimp.

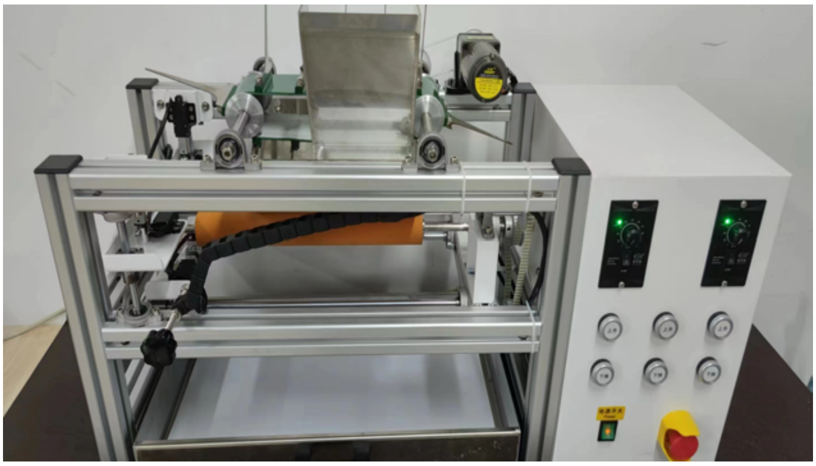

Figure 11. Integrated device for orientation and decapitation of shrimp

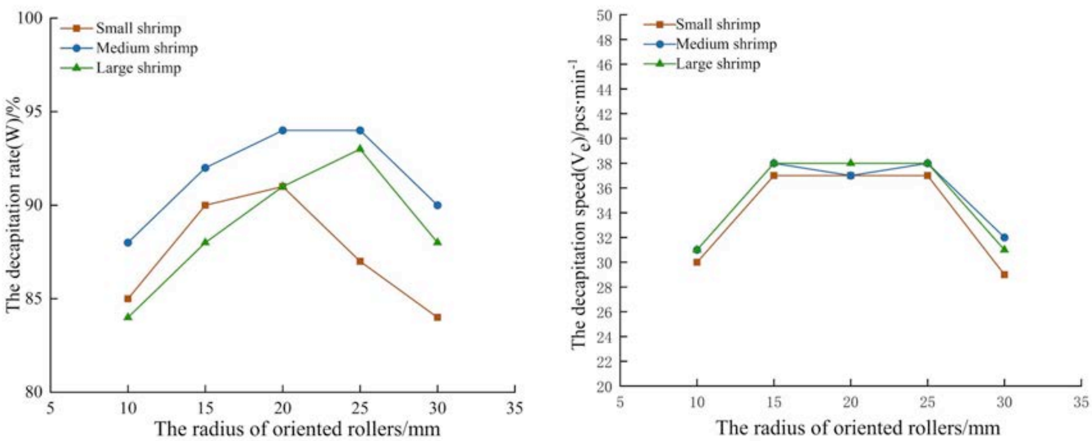

Figure 12. Relationship curves of oriented rollers radius with decapitation rate and decapitation speed.

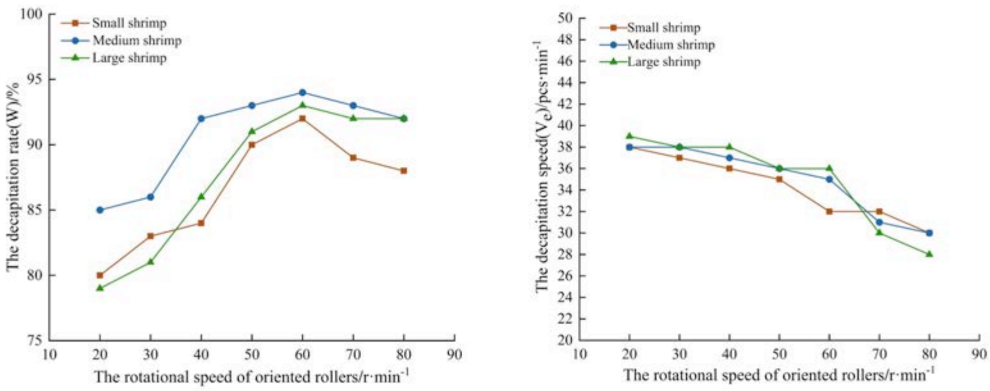

Figure 13. Relationship curves of rotational speed of oriented rollers with decapitation rate and decapitation speed.

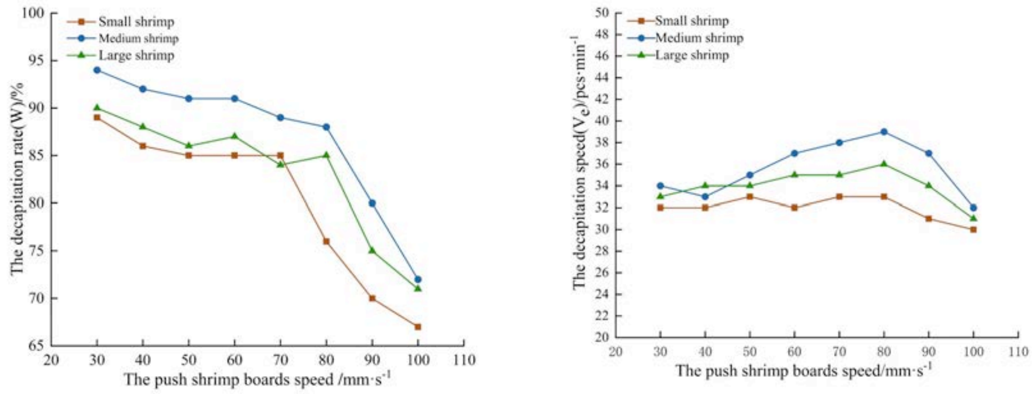

Figure 14. Relationship curves of push shrimp boards speed with decapitation rate and decapitation speed.

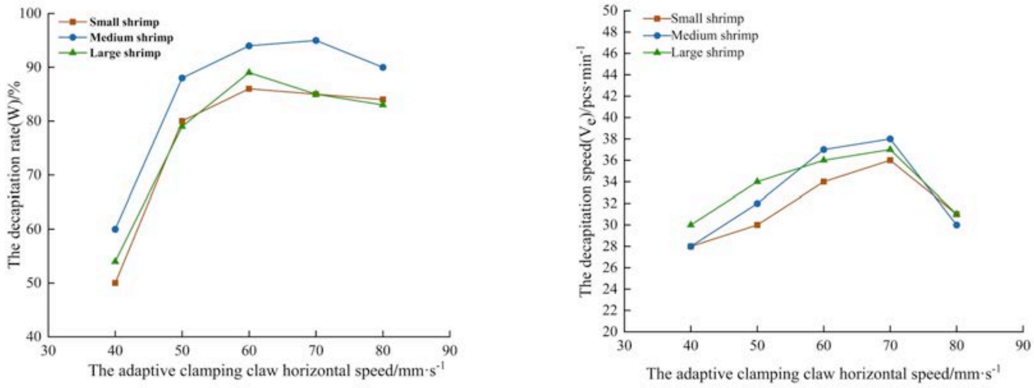

Figure 15. Relationship curves of adaptive clamping claw horizontal speed with decapitation rate and decapitation speed.

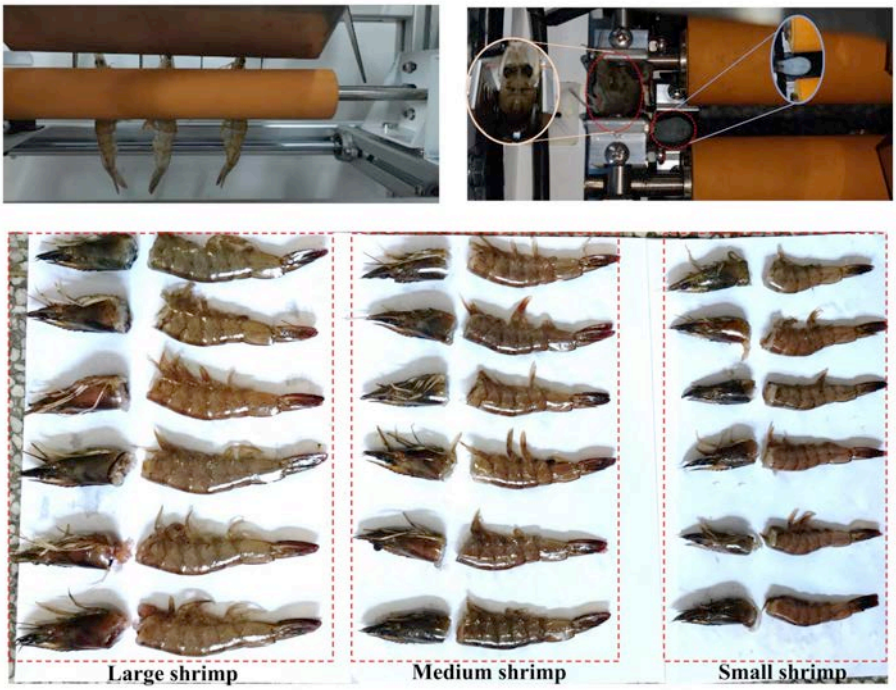

Figure 16. Field test.

Table 1. Measurement results of shrimp external dimensions.

Specification	Maximum thickness of shrimp/mm	The thickness at the center of gravity/ mm	Length of the shrimp body/ mm	Distance from section 5 to shrimp tail/mm
Small shrimp	9.3~11.9	8.7~10.4	64.9~80.8	35.2~40.7
Medium shrimp	11.1~14.3	9.3~11.8	86.1~93.4	42.4~49.2
Large shrimp	13.6~16.5	10.1~12.1	102.6~109.7	53.3~56.2

Table 2. Factors and levels of orthogonal test.

Level	Factors			
	Speed of shrimp pushing boards ($mm\cdot s^{-1}$)	The horizontal speed of the adaptive clamping claw ($mm\cdot s^{-1}$)	Rotational speed of oriented rollers ($mm\cdot s^{-1}$)	Radius of oriented rollers (mm)
1	50	50	40	15
2	60	60	50	20
3	70	70	60	25

Table 3. Orthogonal test results of decapitation rate.

Test serial number		$A_{(a)}$	$B_{(b)}$	$C_{(c)}$	$D_{(d)}$	The decapitation rate /%		
						Small shrimp	Medium shrimp	Large shrimp
1		1	1	1	1	80.20	90.30	85.70
2		1	1	1	1	79.50	88.70	83.20
3		1	1	1	1	81.70	88.90	84.40
4		2	2	1	2	88.70	91.70	89.20
5		2	2	1	2	87.90	90.70	89.00
6		2	2	1	2	89.90	91.30	88.20
7		3	3	1	3	87.90	92.10	86.20
8		3	3	1	3	80.60	90.80	88.80
9		3	3	1	3	86.10	89.50	84.50
10		2	3	2	1	88.70	93.20	89.50
11		2	3	2	1	86.00	92.00	87.20
12		2	3	2	1	88.10	90.70	82.00
13		3	1	2	2	82.40	89.70	81.80
14		3	1	2	2	83.30	90.40	79.20
15		3	1	2	2	78.10	84.20	81.80
16		1	2	2	3	78.60	87.00	82.30
17		1	2	2	3	85.30	88.70	86.20
18		1	2	2	3	77.80	89.50	87.20
19		3	2	3	1	88.70	92.90	89.30
20		3	2	3	1	86.20	93.20	89.00
21		3	2	3	1	85.10	90.80	85.90
22		2	3	3	2	91.50	94.70	92.40
23		2	3	3	2	92.30	94.00	92.80
24		2	3	3	2	90.70	95.10	93.20
25		2	1	3	3	89.40	92.10	89.70
26		2	1	3	3	88.70	90.70	88.10
27		2	1	3	3	79.40	90.00	84.90
Small shrimp	k_1	80.5	82.5	84.7	84.9			
	k_2	88.4	85.4	83.1	87.2			
	k_3	84.3	88	88	83.8			
	R	7.9	5.5	4.9	3.4			
medium shrimp	k_1	88.9	89.4	90.4	91.2			
	k_2	92.2	90.6	89.5	91.3			
	k_3	90.4	92.5	92.6	90			
	R	3.3	3.1	3.1	1.3			
Large shrimp	k_1	84.8	84.3	86.6	86.3			
	k_2	88.9	87.4	84.1	87.5			
	k_3	85.2	88.5	89.5	86.4			
	R	4.1	4.2	5.4	1.2			

Table 4. Orthogonal test results of decapitation speed.

Test serial number	$A_{(a)}$	$B_{(b)}$	$C_{(c)}$	$D_{(d)}$	The decapitation speed/pcs·(min^{-1})		
					Small shrimp	Medium shrimp	Large shrimp
1	1	1	1	1	30	31	30
2	1	1	1	1	30	30	30
3	1	1	1	1	31	31	30
4	2	2	1	2	34	35	34
5	2	2	1	2	35	35	35
6	2	2	1	2	35	36	36
7	3	3	1	3	34	34	34
8	3	3	1	3	33	34	34
9	3	3	1	3	33	33	34
10	2	3	2	1	35	36	35
11	2	3	2	1	35	37	35
12	2	3	2	1	35	37	34
13	3	1	2	2	30	30	30
14	3	1	2	2	30	30	30
15	3	1	2	2	30	31	30
16	1	2	2	3	30	31	31
17	1	2	2	3	31	30	31
18	1	2	2	3	30	31	30
19	3	2	3	1	34	35	34
20	3	2	3	1	34	35	35
21	3	2	3	1	35	35	35
22	2	3	3	2	36	37	37
23	2	3	3	2	37	38	37
24	2	3	3	2	36	38	36
25	2	1	3	3	34	36	34
26	2	1	3	3	34	37	34
27	2	1	3	3	34	36	35
Small shrimp	k_1	30.3	31.4	32.8	33.2		
	k_2	35	33.1	31.8	33.7		
	k_3	32.6	34.9	34.9	32.6		
	R	4.7	3.5	3.1	1.1		
Medium shrimp	k_1	30.7	32.3	33.2	34.1		
	k_2	36.5	33.7	32.7	34.4		
	k_3	33	35.9	36.3	33.6		
	R	5.8	3.6	3.6	0.8		
Large shrimp	k_1	30.3	31.4	33	33.1		
	k_2	35.2	33.8	31.8	33.9		
	k_3	32.9	35.1	35.2	33		
	R	4.9	3.7	3.4	0.9		