

Original Research Paper

Optimization Design of Sea Cucumber Cleaning Parameters by Water Jet

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Abstract: Aiming at the problem that the cleaning effect and surface integrity of the mechanical cleaning process cannot be solved simultaneously in the pretreatment of sea cucumber and according to the requirements of high efficiency, high quality and economy of sea cucumber body surface cleaning, a continuous directional cleaning device for sea cucumber abdomen and back based on the principle of water jet is designed. Through single factor experiment, the influence trend of jet parameters such as jet pressure, target distance and incidence angle on cleaning effect was analyzed. The cleaning parameters of sea cucumber are optimized by $L_9(3^4)$ orthogonal design. The experimental results show that the cleaning effect of sea cucumber is closely related to the impact of water jet. Enhancing the impact of water jet will not only help improve the cleanliness of sea cucumber, but also increase the risk of skin damage of sea cucumber. The influence order of water jet parameters on the cleaning effect of sea cucumber is as follows: Jet pressure > jet target distance > jet incidence angle. When the jet pressure is 3.0 MPa, the jet target distance is 200 mm and the jet incidence angle is 70°, the cleanliness and integrity scores are 8.0 and 8.2 respectively and the comprehensive cleaning effect of this scheme is optimal. This study provides the basis for the research and development of sea cucumber water jet cleaning device and process optimization.

Keywords: Water Jet, Cleaning Device, Parameter Optimization, Sea Cucumber

Introduction

Sea cucumber is rich in a variety of trace elements, mucopolysaccharide and cholesterol free, high protein. It is not only delicious, but also has high nutritional value (Ru *et al.*, 2019) and medicinal value (Fan, 2001; Chunyun *et al.*, 2004). In recent years, the output of sea cucumber in China has increased year by year and the demand for rapid and large-scale mechanized processing technology and equipment is increasingly significant. In this context, many scholars have studied the effects of different processes and parameters (Sun *et al.*, 2017; Liu *et al.*, 2015) on the nutritional quality (Li *et al.*, 2019b; 2018; Meng *et al.*, 2017), texture-characteristics (Xiong *et al.*, 2020; Xin *et al.*, 2019) and edibility (Liu *et al.*, 2018; Shaoxiao *et al.*, 2017) under the

condition of mechanical processing. However, there is no report on the effect of processing technology on the appearance quality of sea cucumber. Body surface cleaning process is one of the important processing procedures to ensure the appearance quality of sea cucumber (Xu *et al.*, 2009). Traditional sea cucumber cleaning is manual, with low cleaning efficiency and poor-quality stability, which cannot meet the needs of large-scale sea cucumber processing. Sea cucumber cleaning and processing mechanization, automation has become an inevitable trend. At present, the cleaning and processing technologies widely used by seafood processing enterprises mainly include washing, immersion, brushing, chemical cleaning, bubble and ultrasonic (Xu *et al.*, 2011; Yan *et al.*, 2019). Although the above methods can realize batch

cleaning of sea cucumber, there are still some deficiencies in cleaning effect. The specific performance is as follows: (1) It is difficult to remove the strong adhesion impurities and rotten tissue on the sea cucumber surface by washing and soaking. Although the cleaning effect can be improved by other cleaning methods, manual secondary sorting is still needed. (2) Brushing method can obtain high surface cleanliness of sea cucumber, but it is easy to cause damage, especially the damage to the stomach and foot of sea cucumber, which affects the appearance quality of sea cucumber products. Therefore, the research of efficient and low loss sea cucumber cleaning technology and equipment is one of the key points in the field of sea cucumber processing.

Water jet cleaning technology is one of the physical cleaning technologies to remove the surface attachments of processed objects/parts in the fields of engineering, agriculture, etc., with the characteristics of rapid and continuous large-scale operation (Fuchs *et al.*, 2019; Liu *et al.*, 2016; Xia *et al.*, 2020). In the processing of aquatic food, fish descaling, shellfish cleaning and impurity removal based on water jet have been gradually studied and applied (Li *et al.*, 2019a; 2020). Due to the directionality of water jet, the directional cleaning of sea cucumber surface can be realized by using this feature, so as to solve the shortcomings of existing methods. It is worth further exploring to construct a new technology and device for sea cucumber cleaning based on the principle of water jet.

Therefore, based on the principle of water jet, a sea cucumber directional cleaning device is designed in this study. The influence trend of water jet parameters on the

cleaning effect of sea cucumber is studied through experiments and the optimization method of water jet cleaning process parameters based on sensory evaluation of sea cucumber cleaning effect is proposed. It provides the basis for the research and development of sea cucumber water jet cleaning device and process optimization.

Design of Water Jet Cleaning Device for Sea Cucumber

Principle of Water Jet Cleaning

The principle of directional cleaning of sea cucumber with water jet is shown in Fig. 1. The sea cucumber is fixed on the transmission device and transported to the cleaning station at a certain speed V . The nozzle in front of the sea cucumber jets pressure water. Under the impact of water jet, the attachments and epidermis on the back and on both sides of the sea cucumber are cleaned away. Because the gastropod part is not impacted by the water jet, the surface of sea cucumber can be cleaned in a directional way. In this process, when the water jet parameters (jet pressure P , jet distance L and jet angle α) change, sea cucumber will be subject to different jet impact force. The cleaning effect of sea cucumber is affected.

Overall Design Scheme and Working Principle

The sea cucumber water jet cleaning device is mainly composed of mechanical body, cleaning device, conveying device, discharging device and protection device. The structure is shown in Fig. 2.

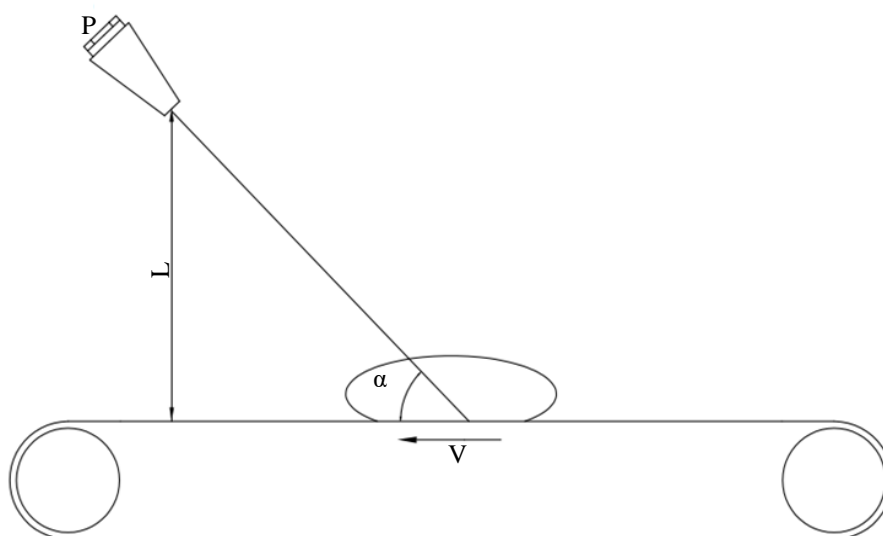


Fig. 1: Schematic diagram of water jet sea cucumber cleaning

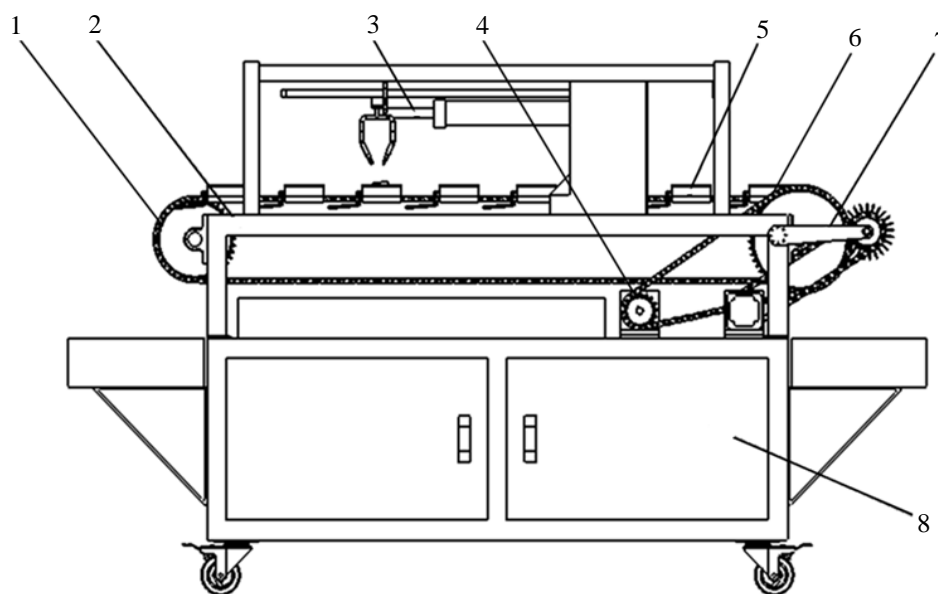


Fig. 2: Structure diagram of sea cucumber cleaning device by water jet. Driven sprocket 2. Frame 3. Nozzle group 4. Driving device 5. Clamping device 6. Driving sprocket 7. Discharging device 8. Water circulation

Experimental Method of Sea Cucumber Cleaning by Water Jet

Materials

The sea cucumber samples used in the experiment are the salted sea cucumber raw materials provided by Dalian sea cucumber processing enterprises in Liaoning Province. The raw materials with the same weight and specifications in the same batch were randomly selected. The single head weight is (25 ± 5) g, the density is (1.15 ± 0.02) g/m³ and the hardness is (10.63 ± 1.78) N.

Instruments and Equipment

The equipment prototype used in the test is shown in Fig. 3.

Test Method

Experiment Process

After the test prototype of the water jet sea cucumber cleaning device runs smoothly, the jet pressure, jet target distance and jet incidence angle are set and then the sea cucumber is placed in the clamping device evenly distributed on the chain conveyor according to the head forward and the tail backward. The stepping motor is adjusted to make the sea cucumber materials transported to the cleaning station to complete the water jet cleaning operation.

Finally, the cleanliness and integrity of sea cucumber of sea cucumber is evaluated refer sensory evaluation to tables. The experiment process of this study is shown in Fig. 4.

Single Factor Test

In this test, the fan-shaped nozzle is selected. The nozzle parameters are 60° of cone angle, 4mm of outlet length and 1mm of outlet diameter. The fixed feed speed is 25mm/s and jet pressure, jet target distance and jet incidence angle are used to conduct single factor experiments on sea cucumber. After the preliminary experiment, the value range of these three control parameters was determined: Jet pressure (1.0-5.0 MPa), jet target distance (160-240 mm) and jet incidence angle (50-90°). The test scheme is shown in Table. 1.

Orthogonal Test

Jet pressure, jet target distance and jet incidence angle are selected as the experimental factors for L₉(3⁴) orthogonal test.

Index and Detection Method

Sensory evaluation method is used to evaluate the surface cleanliness and surface integrity of sea cucumber after cleaning. 10 professionals are invited to evaluate the sea cucumber after the water jet cleaning and take its average score. The sensory evaluation criteria for the surface cleanliness and surface integrity of sea cucumber after cleaning are shown in Tables 2 and 3.



Fig. 3: The experimental prototype of sea cucumber water jet cleaning device

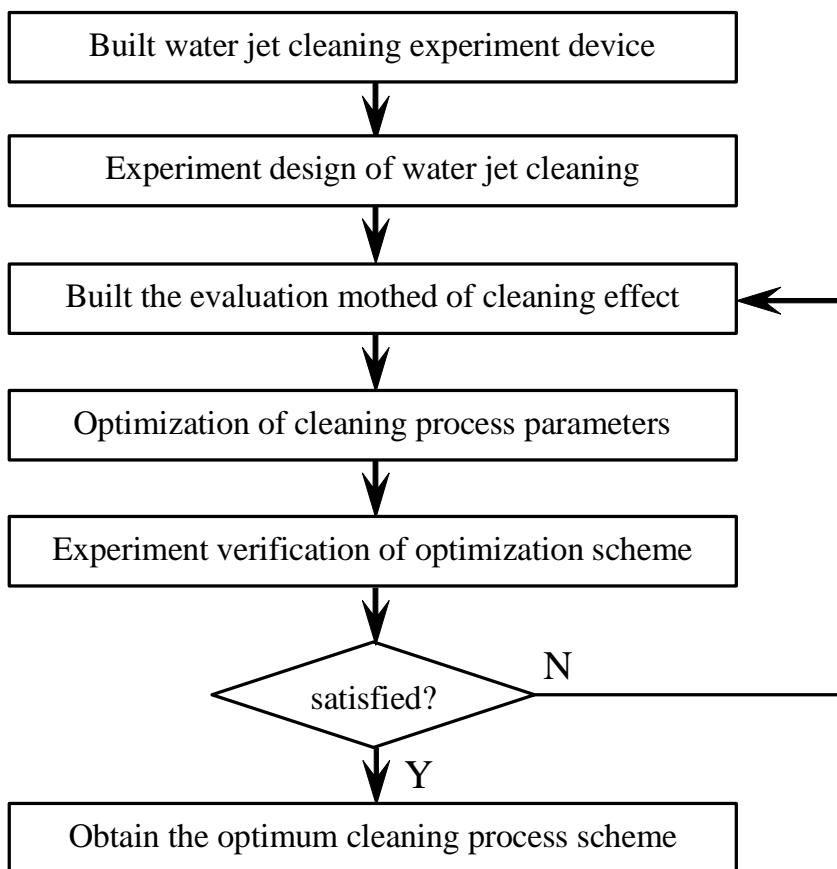


Fig. 4: The experiment process

Table 1: Single factor test scheme

Grouping	No.	Fixed condition	Test condition
Group 1	1	Jet incidence angle: 70°	Jet pressure (MPa) 1.0
	2	Jet target distance: 200 mm	2.0
	3		3.0
	4		4.0
	5		5.0
Group 2	6	Jet pressure: 3.0MPa	Jet target distance (mm) 160.0
	7	Jet incidence angle: 70°	180.0
	8		200.0
	9		220.0
	10		240.0
Group 3	11	Jet pressure: 3.0 MPa	Jet incidence angle (°) 50.0
	12	Jet target distance: 200 mm	60.0
	13		70.0
	14		80.0
	15		90.0

Table 2: Sensory evaluation criteria for surface cleanliness of sea cucumber

Score	Qualitative description
8-10	There is no stain on the surface of sea cucumber and the epidermis was removed evenly.
6-8	There are a few stains on the surface of sea cucumber or a small amount of skin on both sides of sea cucumber are not removed
4-6	There were obvious stains on the surface of sea cucumber or large area of epidermis on both sides of sea cucumber were not removed.
2-4	A large area of stains on the surface of sea cucumber is not removed and the epidermis on both sides of sea cucumber is not removed.
1-2	The stains on the surface of sea cucumber were not removed.

Table 3: Sensory evaluation criteria for surface integrity of sea cucumber

Score	Qualitative description
8-10	No damage is found on the surface of sea cucumber.
6-8	There are a few honeycomb spots on the surface of sea cucumber.
4-6	There is a large area of honeycomb or a small number of shallow cracks on the surface of sea cucumber.
2-4	The skin of sea cucumbers is detached in large area or there are obvious cracks on the surface of sea cucumbers.
1-2	The surface of sea cucumber is deeply damaged and the internal tissue is clearly visible.

Test Results and Analysis

Single Factor Test

It can be seen from Fig. 5 that the score of sea cucumber surface cleanliness increases with the increase of jet pressure, while the score of sea cucumber surface integrity decreases with the increase of jet pressure. With the increase of jet pressure, the impact force of jet also increases and the stains on the sea cucumber surface fall off under the shear force of the water jet. However, when the water jet shear stress exceeds the shear failure strength of the sea cucumber surface, the sea cucumber surface will receive shear failure and form honeycomb damage points. When the shear force is further increased, cracks in the top-down direction will appear on both sides of the sea cucumber.

It can be seen from Fig. 6 that with the increase of jet target distance, the impact force of jet will decrease and the score of surface cleanliness of sea cucumber will decrease, while the impact force of jet will decrease. Meanwhile, the damage of sea cucumber surface is also reduced and the score of sea cucumber surface integrity will increase.

According to Fig. 5 and 6, the cleaning effect is related to the intensity of jet impact force, which is determined by

the jet pressure and jet target distance, but there are some differences in their modes of action. The change of jet target distance not only affects jet impact intensity, but also changes the uniformity of jet impact. The farther the distance between jet target is, the better the uniformity of jet is. In order to improve the surface integrity score, the strategy of increasing jet target distance should be given priority compared with the strategy of reducing jet pressure.

According to Fig. 7, with the increase of jet incidence angle, the vertical component of jet impact force becomes large, while the horizontal component becomes small. The surface cleanliness score of sea cucumber is mainly related to the vertical component of jet impact force. The surface cleanliness score of sea cucumber increases linearly with the increase of jet incidence angle. In terms of surface damage, excessive vertical component of jet impact force will lead to honeycomb or cracks on the back surface of sea cucumber. However, if the horizontal component of the jet impact force is too large, the skin of the front-end of the sea cucumber will be torn. Therefore, the surface damage of the sea cucumber will be caused by too large or too small incident angle of the jet. When the jet incidence angle is 70°, the sea cucumber surface integrity score reaches the peak.

Orthogonal Test

The L₉(3⁴) orthogonal test is designed with the jet pressure, jet target distance and jet incidence angle as the factors and the cleanliness score and integrity score of sea cucumber surface as the index. The factor level table is shown in Table 4.

It can be seen from Table 5 that the order of influence of each factor on cleanliness score is: Jet pressure > jet target distance > jet incidence angle.

The parameter combination of the optimal cleaning score is A₃B₁C₂, that is, the jet pressure is 4.0 MPa, the jet target distance is 180mm and the jet incidence angle is 70°. The order of influencing factors on the integrity score is: Jet pressure > jet target distance > jet incidence angle. The parameter combination of the optimal integrity score is A₁B₃C₁, that is, the jet pressure is 2.0 MPa, the jet target distance is 220mm and the jet incidence angle is 60°.

Table 4: Factor level

Level	A Jet pressure (MPa)	B Jet target distance (mm)	C Jet incidence angle (°)
1	2.0	180	60
2	3.0	200	70
3	4.0	220	80

Table 5: Orthogonal test scheme and results

No.	A	B	C	Cleanliness score	Integrity score
1	1	1.00	1.00	7.50	8.2
2	1	2.00	2.00	6.80	8.9
3	1	3.00	3.00	6.00	9.4
4	2	1.00	2.00	8.90	6.8
5	2	2.00	3.00	7.80	7.5
6	2	3.00	1.00	6.90	8.9
7	3	1.00	3.00	9.80	5.0
8	3	2.00	1.00	9.00	6.8
9	3	3.00	2.00	8.20	7.3
Cleanliness	K ₁	6.77	8.73	7.80	
	K ₂	7.87	7.87	7.97	
	K ₃	9.00	7.03	7.87	
	R	2.23	1.07	0.17	
Integrity	K ₁	8.83	6.67	7.97	
	K ₂	7.73	7.73	7.67	
	K ₃	6.37	8.53	7.30	
	R	2.46	1.86	0.67	

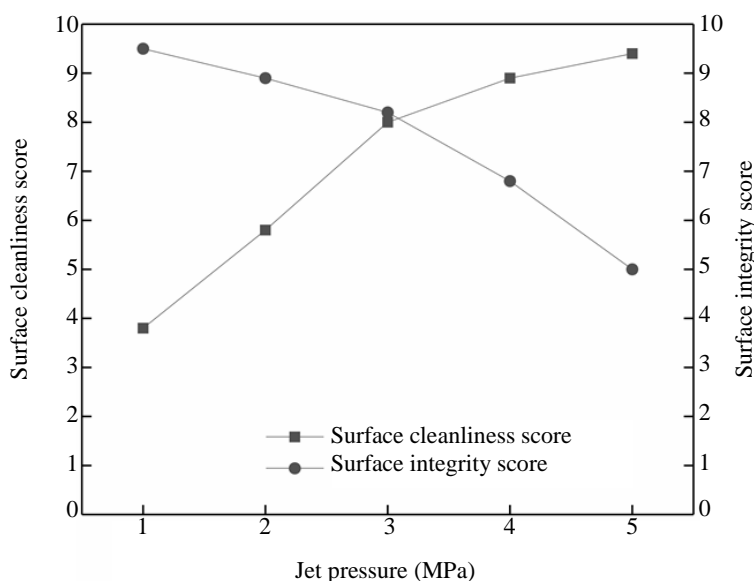


Fig. 5: The effect of jet pressure on the cleaning effect of sea cucumbers

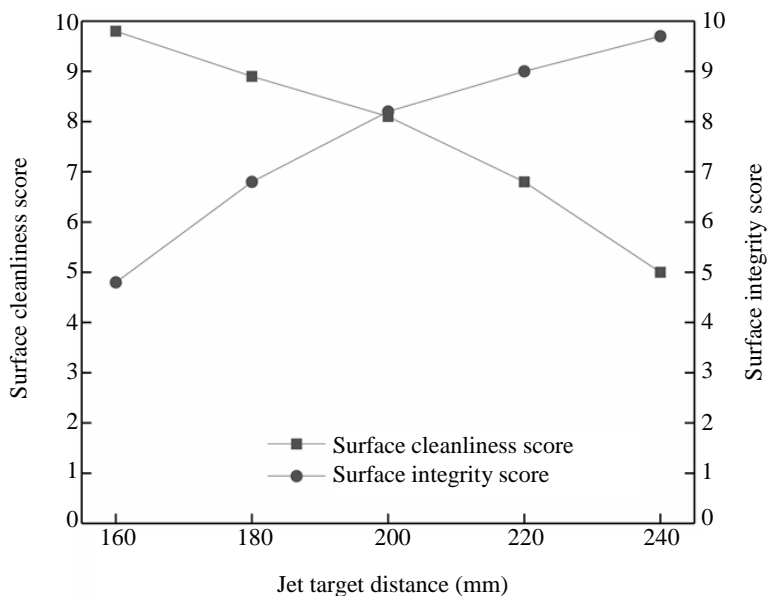


Fig. 6: The effect of jet target distance on sea cucumber cleaning effect

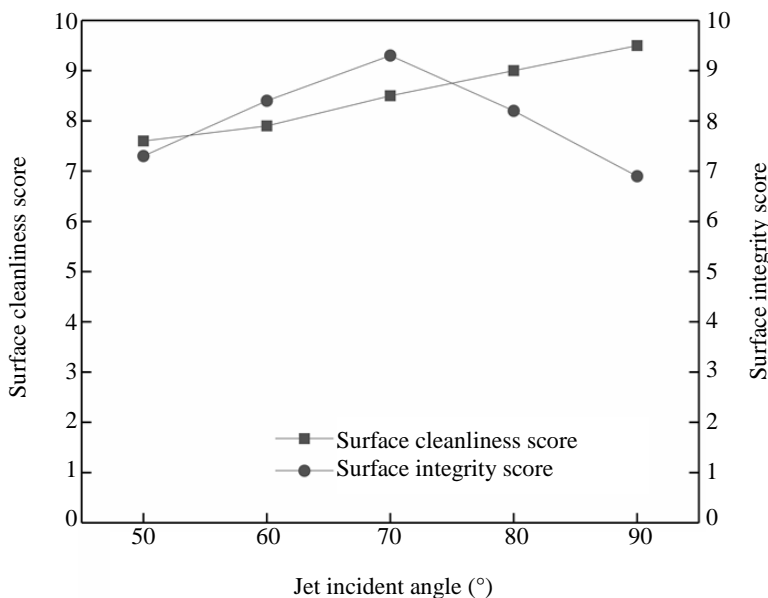


Fig. 7: The effect of jet incident angle on the cleaning effect of sea cucumber

The experimental results show that when the parameter combination of $A_3B_1C_2$ is used for sea cucumber water jet cleaning, the sea cucumber surface cleanliness score reaches 9.7. The sea cucumber surface has no stain and the cleaning uniformity is good. However, the surface integrity of sea cucumber is only 5.2 and honeycomb and cracks are obvious on the surface of sea cucumber. The qualified rate of processed products was too low. When the parameter combination of $A_1B_3C_1$ is used, the sea cucumber surface integrity score reaches 9.5. The sea cucumber skin is not damaged

and the sea cucumber surface cleanliness score is only 6.0. Moreover, there are obvious stains and unshelled areas on both sides of the sea cucumber surface. In actual production, the sea cucumber with this cleaning effect cannot meet the requirements of the apparent quality of sea cucumber and manual secondary cleaning is needed, which increases the cost of cleaning. According to the characteristics of water jet cleaning, a compromise should be made between the cleaning degree and damage degree of sea cucumber surface when the technological standard of sea cucumber cleaning is established.

Optimization of Process Parameters

According to the characteristics of water jet cleaning, it is necessary to compromise between the surface cleanliness degree and the surface integrity degree when building the cleaning technology standard. Using the response surface method, multiple quadratic equation regression analysis is conducted to establish the functional relationship between the surface cleanliness degree Y_1 and the surface integrity degree Y_2 :

$$Y_1 = 8.2 + 1.18x_1 - 0.41x_2 + 0.46x_3 - 1.08x_1x_2 + 0.075x_1x_3 - 0.075x_1^2 - 0.05x_2^2 - 1.05x_3^2 \quad (1)$$

$$Y_2 = 6.52 - 1.14x_1 + 0.46x_2 - 0.42x_3 + 1.12x_1x_2 - 0.15x_1x_3 - 0.05x_2x_3 + 0.18x_1^2 + 0.28x_2^2 + 0.85x_3^2 \quad (2)$$

Normalize Equations (1) and (2) and set the weight coefficients of Y_1 and Y_2 as 0.6 and 0.4, respectively. Finally, the comprehensive optimization equation is obtained:

$$Y = 7.528 + 0.252x_1 - 0.062x_2 + 0.108x_3 - 0.2x_1x_2 - 0.015x_1x_3 - 0.02x_2x_3 + 0.027x_1^2 + 0.082x_2^2 - 0.29x_3^2 \quad (3)$$

According to the comprehensive optimization equation, the optimal cleaning process parameters were obtained as follows: Jet pressure 3 MPa, jet target distance 200 mm, jet incidence angle 70° and the score of surface cleanliness and integrity of sea cucumber are 8.0 and 8.2, respectively. Under the above technological parameters, three confirmatory experiments are carried out and the test results of the score of surface cleanliness and integrity of sea cucumber are 8.1 and 8.1, respectively. The effectiveness of the optimization scheme was verified.

Conclusion

- (1) According to the principle of water jet cleaning, the design scheme of sea cucumber cleaning device with the multi-functions of conveying, cleaning, protection and unloading is put forward, which realizes the continuous directional cleaning of the front and back of sea cucumber.
- (2) Based on the experimental prototype, the cleaning experiment of sea cucumber was carried out and the experiment results showed that the increase of jet pressure and the decrease of jet target distance can improve the cleaning degree of sea cucumber, but also increase the possibility of sea cucumber damage. The larger the jet incidence angle is, the higher the cleaning degree of sea cucumber is and the larger and smaller jet incidence angle will increase the risk of sea cucumber damage. Through range analysis, the primary and

secondary factors affecting the score of cleanliness and integrity are jet pressure, jet target distance and jet incidence angle.

- (3) The parameters of sea cucumber water jet cleaning were optimized. When the jet pressure is 3.0 MPa, the jet target distance is 200 mm and the jet incidence angle is 70°, the cleanliness and integrity scores are 8.0 and 8.2 respectively. The comprehensive cleaning effect of this scheme is optimal.
- (4) On the basis of the method in this study, the structure design and automatic control method of sea cucumber body surface cleaning device can be further studied. At the same time, the method in this study can provide a research basis for the development of mechanized and automatic cleaning equipment for typical seafood (fish, shellfish, sea cucumber, etc.).

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Author Contributions

Xu Zhang and Changyuan Zhang: Designed and performed the experiments, analyzed the data and prepared the paper.

Fei Gao and Weiwei Xia: Collection and/or assembly of data.

Peng Zhang and Zixiang Xu: Participated to collect the materials related to the experiment and revised the manuscript.

Ethics

The authors declare their responsibility for any ethical issues that may arise after the publication of this manuscript.

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