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Research on Pearl Detecting and Grading Based on Monocular Multi-view Machine Vision

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Authors' contributions

This work was carried out in collaboration between all authors. Author YT designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors SX and ZZ managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Pearl is a non-planar object and its surface has a certain degree of curvature. It is necessary to obtain the image of the entire surface of a pearl for the aim to achieve the grade based on size, shape, luster, blemish and color. This paper designed a detecting device to solve this problem and complete the pearl's grading automatically.
Methodology: In this paper, an imaging apparatus of monocular multi-view was designed by putting a symmetric bucket cavity, which was made of 4 planar mirrors in front of the camera. The surface of a pearl will be captured from different perspectives using this device. Then a series of views which reflect the quality of a pearl could be achieved by image processing. Finally feature fusion will be utilized to determine the quality of the pearl.
Conclusion: Experimental results show that the image of the entire surface of a pearl could be obtained in a unified color system using the proposed device. Besides, the device accomplishes pearl online detecting and grading according to the quality indicators such as size, shape, luster, blemish and color.

Keywords: Machine vision; monocular multi-view; digital image processing; pearl quality detection; online grading.

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1. INTRODUCTION

Pearls have a long history of employment and cultivation in China. By 2005, the annual output of freshwater pearls has reached about 1500 tons, which accounts for 95 percent of the world's total output, and 400~500 tons of them are exported, taking up more than 90 percent of the trading volume in international market. But the grading method adopted by the whole industry is still in the stage of artificial detection. Due to the small volume and large number of pearls, the grading work has low efficiency and couldn't make an appropriate, effective and stable quality control.

By the use of machine vision, these aforementioned problems could be solved effectively. Recently many industries have proved that the detection of production by machine vision is effective [1-5]. In China, there are many experts doing researches on machine vision for completing the automatic detection and classification of pearls. Ge Li [6] and his team have studied the shape of pearls using machine vision. They used the Fourier series and fuzzy recognition to achieve the shape classification and the largest error judgment rate was 33.3%. Shuchang Xu [7] designed a system of automatic classification for the pearls based on the machine vision. The system used four cameras to capture the falling pearl and make the smoothness detection by image processing. Huawen Zheng [8] adopted the computer vision to classify pearls' shape. His research also utilized the Fourier series and the recognition result was based on the Euclidean distance between the peals under checking and the ones in the standard template library. Jilin Zhou [9] studied the collection for the pearls' image and detection for the pearl's blemish with the machine vision. He used a new filter based on space geometry to enhance defect contrast. Then region-grow was used to accomplish the smoothness detection. All the studies described above have made a contribution to the automatic detection of pearls which used the technology of machine vision.

As pearl is a sphere of non-planar target object, it's necessary to obtain the whole sphere images of the pearl for classification. Therefore, the detected pearl needs to be captured multiple images from different perspectives. Document [6,8,9] captured images from different perspectives by rotating the pearl. This method will cost a lot of time and can't meet the requirement of online grading. Document [7] put forward that shooting the surface of the falling pearl from multi-angle. But it needs to configure four high-speed cameras, which will increase the cost of hardware. Furthermore, this scheme requires more than one high-speed camera to capture the images of the falling pearl in real time. For this reason, it has a high requirement for the precision of controlling the device. Above all, the pearl images are captured under its free-falling, so the captured images have adverse effects on the detection of the pearl's luster and blemish. At last, it is not easy for multiple cameras to keep consensus of the color system.

The pearl's online detecting and grading device need to solve these follow questions: 1) How to design a kind of device that not only costs less money, but also gets images quickly; 2) How to accomplish a real-time detection of pearl's appearance quality; 3) How to reduce the interference of environment ambiguity and the reflection of pearl's surface; 4) How to utilize the pipeline to improve the detection speed.

Therefore, this paper designs a kind of pearl detecting and grading device based on monocular multi-view machine vision. The device could obtain the whole sphere images of the pearl by one camera. So, it greatly reduces the production cost. Furthermore, without rotating the pearl, it has the short response time of grading.

2. THE DESIGN OF MULTI-VIEW STEREO VISION MONOCULAR DEVICE

2.1 The Composition of the Device

In order to obtain the entire surface of pearl's image, this paper designs a monocular multiple angles of stereo vision device that consists of a CMOS camera and four plane mirrors. The device shown in Fig. 1 could obtain 5 perspectives of a pearl's surface image through one camera. Specific method is as follows: place the symmetrical bucket cavity which made by 4 plane mirrors in front of the camera and mirrors are toward inside. The object light is reflected by four plane mirrors and projects onto different regions of the camera's image plane. Then it will projects multiple images on the camera's image plane and generates the monocular multi-view stereo images. These images are equivalent to the plurality of images from different perspectives and the device is equivalent to a multi-view stereoscopic vision device. The device could get the images of the pearl surface from four different perspectives through a single imaging. Due to this advantage, it provides a great technical support for detecting pearl's quality indicators, such as the pearl's size, shape, luster, blemish and color.

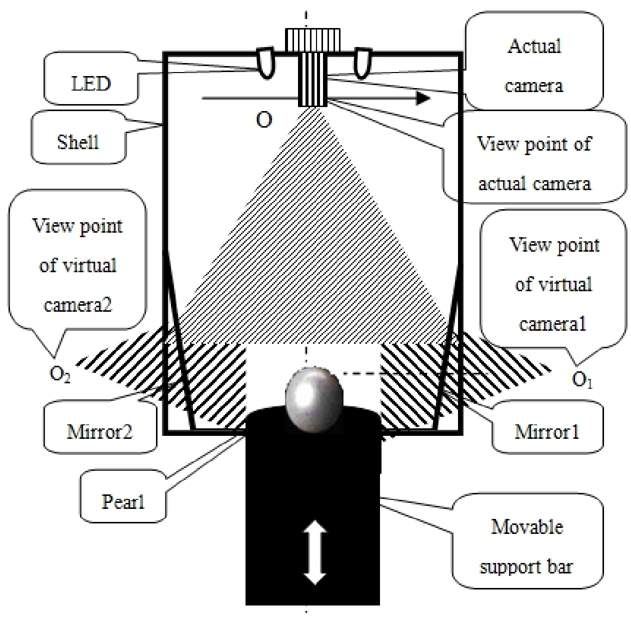

Fig. 1. Monocular multi-view stereo vision detection

Fig. 1 is a schematic diagram of monocular multi-view stereo vision system. It is composed by the camera and mirror bucket cavity. The bucket cavity is composed by four planar mirrors. The mirrors are all isosceles trapezoids and toward to the inner side of the cavity. Besides, the cavity's central axis coincides with the main optical axis of the camera. The camera lens is probed into the cavity from the top of the device. The incident light of the lens is composed by the direct lights and the reflected lights. The direct lights which get through the cavity are projected in the central region of the camera projection plane, and pearls are placed into the central area by movable support bar. The reflected lights are projected in the peripheral areas of the camera projection plane and the projection areas of the four mirrors are different from each other. Accordingly, the image captured by this device contains a plurality of images of the measured pearl, and these images as shown in Fig. 2 are from five different perspective projection points. There are five different perspective projection points. The point which is direct imaging in the camera is point O and it is the real camera's perspective projection point. The other four (O1、O2、O3 and O4) are perspective projection points of the virtual cameras which are constituted by the real camera and the mirrors. Because 5 different angles of a pearls are imaged with one camera, this device has the consistent internal parameters and color system.

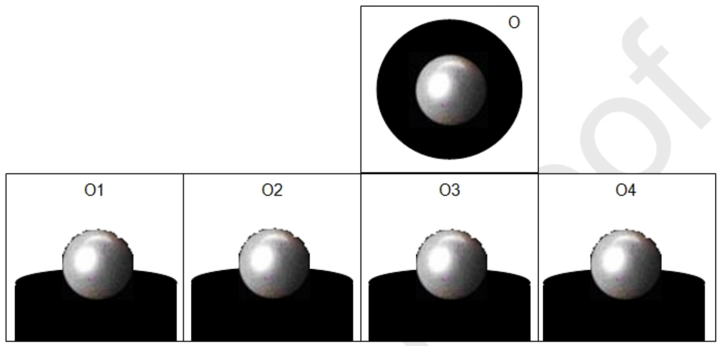

Fig. 2. Pearl images captured by the different view points

To reduce the interference of environment, the detection device of monocular multi-view stereo vision in this paper is closed by a shell.

2.2 The Design of lighting Source

Design of lighting source is one of the most important parts in detecting device by machine vision. The system in this paper is double-dot lighting. We chose the white LED as the lighting source and it was placed at the camera's level. The angle between LED and the primary optical axis of camera is 9°. The four plane mirrors make the reflected light on the pearl's surface uniform, shadowless, non-reflective and bright so it will meet different testing indexes of lighting requirement. The detected pearl should be placed on the movable support bar and then it can be put into the stereo-vision device through the movement of the support bar.

2.3 The Calibration of Vision Device

In general, the calibration of vision device demands multiple images to get the accurate calibration of all model parameters. In this paper, the imaging apparatus of monocular multi-view utilizes plane mirrors to shoots a multi-view image which includes multiple images of the calibration board. It follows from the reflection principle of plane mirror that the images of the calibration board equals to multiple images that are gained through the projection on projection plane by the same calibration board at different locations. Therefore, the use of the multi-view projected images of one calibration board is equals to the calibration of multiple calibration board images on calibrating internal parameters of the camera. The image includes five independent calibration boards which could gain high-precision calibration results. More details about the camera calibration and perspective projection transform methods are introduced in some related books on digital image processing and computer vision. This paper utilized the Zhang Zhengyou calibration method to calibrate the camera. The average error of five different views is 0.2320 pixels.

3. THE DESIGN OF PEARL ONLINE DETECTING AND GRADING DEVICE

To detect and grade the pearls automatically, we have to design the action devices which are used for automatic detection and grading. As Fig. 3 shows, the devices include the feeding action device which is used to transform the pearl to the moveable support bar of the device (The feeding action device should ensure that every time feeding one pearl and putting it at the accurate position—on the moveable support bar).The deliver action device is used to lift the pearl up to the detection box for visual analysis, classification and grading and the discharge action device is used to deliver the checked pearl on the moveable support bar to the grading result input. The microprocessor is used for visual analysis, classification and grading of the detected pearl on the flap. The grading action device is used to convey the checked pearl to the corresponding pearl classification container according to the grading results.

There is an inter-operation between feeding action device and deliver action device. When the deliver action device is pushed down to a certain position, the detected pearls in the feeding pipe of feeding action device will inflow to the flap of moveable support bar automatically because of gravity. Meanwhile, the moveable support bar of deliver action device will change the moving direction immediately and send the flap up to detection boxes for visual analysis. We utilize the transmitting gear to control the moveable support bar. By changing the positive and negative direction of the transmitting gear, we can easily control the up-and-down movement of the moveable support bar. The detected pearl will be up-sent to the detection boxes when the support bar reaches the upper limit position. By contrast, when it reaches the lower limit position, the feeding pipe will not be blocked and the pearl from the feeding pipe will inflow to the flap due to the gravity. Discharge action device consists flap, spring hinge and traction type electromagnet. When traction type electromagnet is energized, it can overcome the elasticity from the spring hinge to open the flap, and because of the gravity, the pearl will fall to the inner hole of moveable support bar and then inflow to the grading result input. When the electromagnet loses power, the flap will be closed by elasticity of the spring hinge to ensure that the pearl which on the flap will not fall into the hole of support bar. At last, feeding action device ensure to send one pearl to feeding pipe in each action, so that only one pearl can fall in the flap of moveable support bar.

Now we will introduce the whole process of these actions mentioned above.

- Step (1) Feeding action device send one pearl to the feeding pipe. When the moveable support bar of deliver action device reaches the lower limit position, the pearl in feeding pipe inflow into the flap of deliver action device rely on its own gravity. Meanwhile, feeding action device gets ready to send a pearl into the feeding pipe.
- Step (2) When the movable support bar of deliver action device reaches to the upper limit position, the detected pearl will be ascended to the detection device and the device will take pictures from the five different perspectives.
- Step (3) After capturing an image of the pearl, the device starts the discharge action device. It makes the pearl which are placed on the flap of the movable support bar fall into the hole of the movable support bar and inflow into the grading result input.

Step (4) According to the classification result, the device controls the grading action device to turn to the corresponding classification container. Then it controls the electromagnetic switch of grading action device to make the pearl flow into the corresponding classification container.
Step (5) Return step 1.

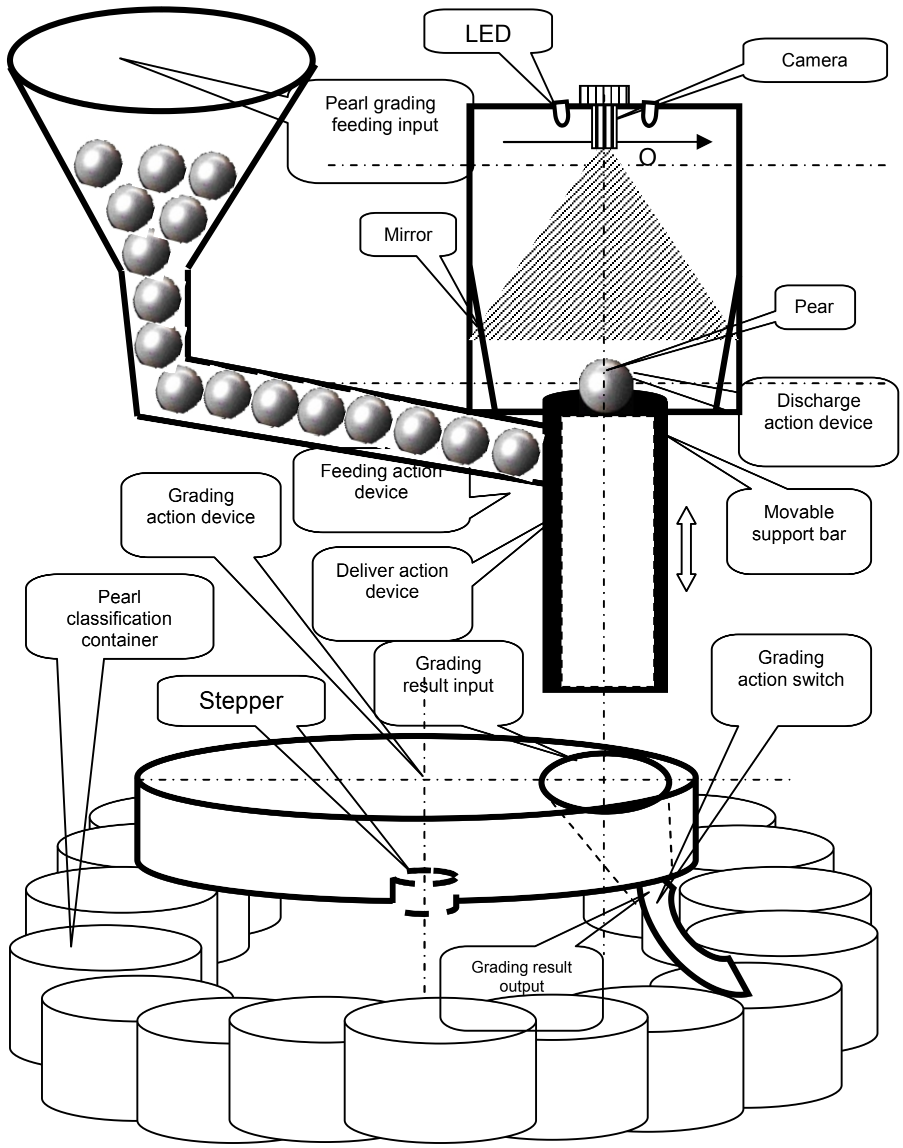

Fig. 3. Pearl online detecting and grading system based on machine vision

4. THE ACTION SEQUENCE OF PEARL ONLINE DETECTING AND GRADING DEVICE

According to the sequence of pipeline, following content explains the sequential relationship between the five actions. As shown in Fig. 4, firstly, the movable support bar of the deliver action device moves up-and-down, and the time which spends on moving from the upper limit to the lower limit is T1.

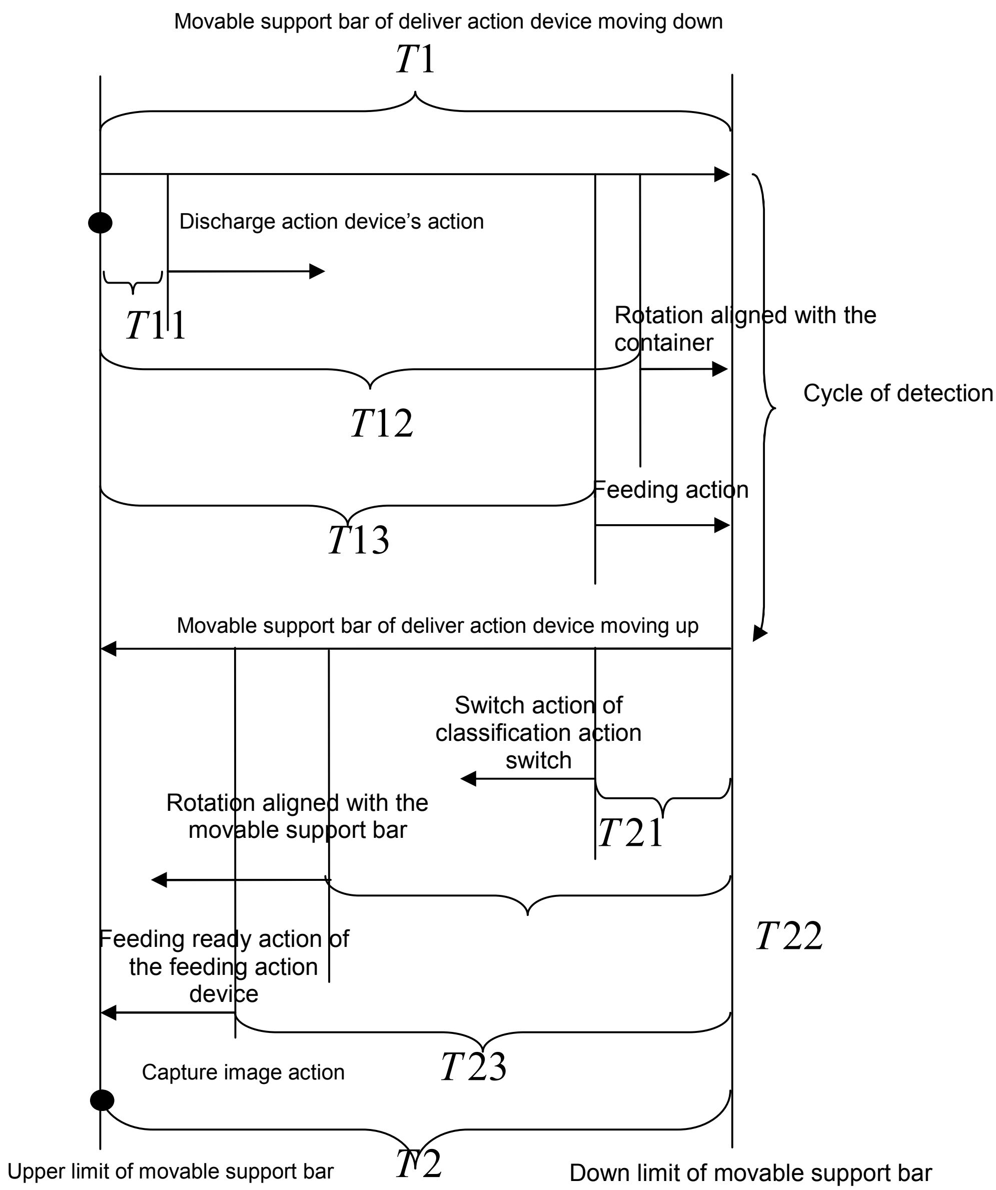

Fig. 4. Pearl online detection devices action sequence based on machine vision

It takes time of T2 to move from the lower limit to the upper limit, and T2 equals to T1. When the movable support bar of the deliver action device begins moving from the upper limit, the image capture device is triggered to capture an image of the pearl. Then the picture will be analyzed, detected and classified. After time of T11 the discharge action device is triggered to make the pearls which are placed on the flap of the movable support bar fall into the hole of the movable support bar and inflow into the grading result input. After time of T12, the grading action switch is triggered to rotate based on the result of classification. And it leads the grading result input to move to the right classification container. Thus, the analysis, detection and classification recognition of pearls must be finished in T12. After T13, the pearl is on the feeding pipe fall onto the flap where is on the movable support bar of the deliver action device. When the movable support bar moves to the lower limit, it changes direction to begin moving up. After T21, the electromagnetic switch of grading action device is triggered and makes the pearl flow into the corresponding classification container. After T22, the grading action device is triggered to turn until the classification input entrance comes to the right position. Then after T23, the feeding action device is triggered to feed a pearl into the feeding pipe. When the movable support bar moves to the upper limit, it changes its direction and begins to move down. The device reciprocates and finishes one pearl's detection on each cycle.

5. PEARL'S IMAGE ANALYSIS, DETECTION AND CLASSIFICATION

According to the national standard of pearl classification---GB/T18781-2008[10], pearl's classification is based on pearl's kind (seawater, freshwater). And pearl is evaluated on six aspects: color, size, shape, glossiness, smoothness, pearl layer's thickness (pearl which has core), especially color, size and smoothness grade are identified according to national standard samples. Commonly it's divided into four grades. In this paper, the device classifies pearls according to the national standard.

Machine vision can detect and classify pearl's quality in five aspects, including color, size, shape, luster and smoothness. In the action-sequence of detection and classification shown in Fig. 4, the image analyzing, detection and classification must be completed in T12. Fig. 5 is the block diagram of the hardware and software systems for online pearl detecting device based on monocular multi-view machine vision. As the red dotted line shown in Fig. 5, 5 threads are utilized for image analyzing and processing of the five quality factors of the detected pearl including color, size, shape, luster, smoothness at the same time. In order to improve the speed of image processing, 4-core microprocessor chip PC is utilized in this paper. And the programming language is JAVA. We adopt its multi-threading mechanism as well.

When pearl is detected in the detection chamber, the light conditions, the gray value of the image background and the intensity of the reflected light are constant in a certain area. In this paper, the Ostu algorithm is utilized to do the image segmentation, and the corrosion algorithm is utilized to remove the outermost halo of the pearl region.

Through the image segmentation, the device gets the pearl's pictures and according to the national standard to detect the five qualities about color, size, shape, glossiness, smoothness in the fives threads.

The color and glossiness detection could use the HSL (hue, saturation, lightness) color model. Freshwater pearl basically has 3 kinds of color: white, red and purple. Each color has the different value of H. So the average value of H could be obtained to achieve the coarse classification of pearl color. Furthermore, each color has different saturation. So the value of S could be obtained to achieve the precise classification of pearl color. The glossiness could be detected by the value of L because the glossier of the pearls is brighter.

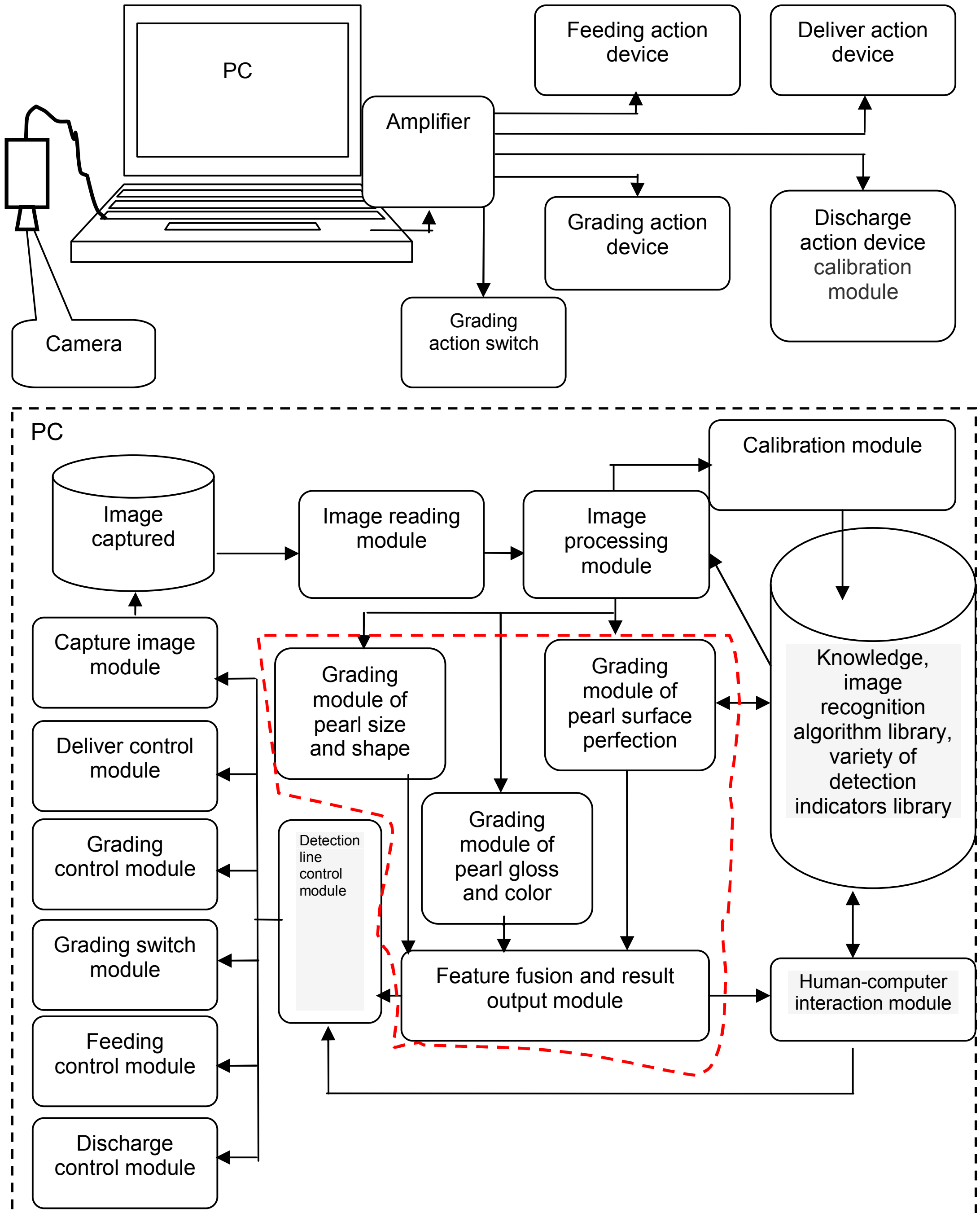

Fig. 5. Block diagram of the hardware and software systems for pearl online detection and classification based on monocular multi-view machine vision

The size and shape detection could be accomplished by calibration and Fourier transform.

This will be introduced in detail in Section 6. And LoG operator (Laplacian of Gaussian operator) could be utilized to make the smoothness detection. LoG operator is an edge detection operator and it is sensitive to the mutations in an area. So the blemish on the surface of a pearl will be detected effectively.

In this paper, it will be mainly talked about to detect the size and shape of a pearl. The color, glossiness and smoothness detection will be introduced in the following paper.

6. PEARL'S SIZE AND SHAPE DETECTION

A pearl always has different shapes when captured from different perspective. In machine vision processing, the plane which can mostly reflect the pearl's shape is called the characteristic plane. In this paper, five different perspectives of the pearl were detected. According to the five images, if there is a sharp-headed, the testing result will be sharp-headed. If there is a flat-headed shape, the testing result will be flat-headed shape. And if there are only elliptic or round shapes, the classification will follow the priority order of ellipse first.

Pearl's edge is a closed curve, so the coordinates of each point on the edge is a periodic function. And the period is the perimeter of pearl's edge. According to theory of Fourier series, the function can be expanded into a Fourier series. In this paper, we utilize the Fourier series coefficients to describe the shape of the pearl. Because of the variety of pearl's size and shape position, the functions achieved by Fourier transform are not comparable. Therefore, before the Fourier transform, the pearl's image need to be pretreated.

Firstly, pearl's centroid in each perspective image should be calculated in order to transform it to the polar coordinate system. Then, we map the pearl's image to polar coordinates system and seek the radius sequence $r(k),\{k=1,2,\cdots,360\}$. When the image is rotated, the pixels on the circle also rotate, so the pearl's contour which is mapped to polar coordinate system has the rotation invariant. After that, pearl's contour need to be normalized to make sure it has invariance in size. Normalization formula is as follows,

$$r_q(k) = r(k) / r_{\max} \qquad (1)$$

$r_q(k)$ is the normalized radius $r(k)$ is the radius sequence and $r_{\max}$ is the maximum radius.

After normalization, we utilize the formula (2) to process the radius sequence by Discrete Fourier transform,

$$F(h) = \sum_{k=1}^{n} r_q(k) e^{-j2\pi kh/n} \qquad h = 0,1,2,\ldots \qquad (2)$$

In the formula, $r_q(k)$ is normalized radius, $F(h)$ is the Discrete Fourier transform of $r_q(k)$.

Because $F(h)$ is symmetrical, we just need to calculate the first n/2 values. On the other hand, it is found by experiments that the contour information is mostly concentrated in the first eight $F(h)$. Abandoning the subsequent $F(h)$ doesn't influence the contour information. In order to improve the computing speed, the first eight $F(h)$ is used to represent the main information of pearl's shape and pattern recognition is also applied to recognize pearl's shape.

In this paper, we picked ten pearl samples of each shape contain round, ellipse, flat-head and sharp-head for image processing. The first eight $F(h)$ of each sample is calculated by computer. Then this paper took average shape of each sample as pearl's characteristic parameters and put them to the storage unit of computer.

In order to achieve pearl shape's fuzzy classification, this paper utilizes formula (3) [6] which is derived from fuzzy pattern recognition to calculate each shape's membership μ_{Wn} for every detected pearl,

$$\mu_{Wn} = \frac{1}{1 + \left| F(h) - \overline{F}(h) \right| \overline{F}(h)} \tag{3}$$

In the formula, $\overline{F}(h)$ is the Discrete Fourier transform of each sample's $r_q(k)$. $F(h)$ is the Discrete Fourier transform of each detected pearl's $r_q(k)$. μ_{Wn} is each shape's membership.

According to formula (3), we can achieve pearl's membership matrix μ,

$$\mu = \begin{pmatrix} \mu_{10} & \cdots & \mu_{17} \\ \vdots & \ddots & \vdots \\ \mu_{40} & \cdots & \mu_{47} \end{pmatrix} \tag{4}$$

Weight coefficient vector can be represented by formula (5),

$$\alpha = [\alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6, \alpha_7]^T, \text{ and } \sum_{k=0}^{7} \alpha_k = 1 \tag{5}$$

So that detected pearl belonging to shape W's membership vector can be calculated by formula (6),

$$\mu_W = \mu \cdot \alpha = [\mu_1, \mu_2, \mu_3, \mu_4]^T \tag{6}$$

In the recognition, the maximal μ_W's subscript is in accordance with the classification result.

At last, the characteristic plane is determined by the classification result. The order is sharp-head, flat-head, ellipse and round. The characteristic plane's shape is the final recognition result.

According to national standard of pearl classification——GB/T18781-2008 [10], the size of round pearl is represented by minimum diameter and the size of other shape's pearl is represented by maximum size multiply minimal size. In this paper, we utilize the radius sequence $r(k)$ which is achieved above to calculate the maximum diameter $D_{\max}$ and minimum diameter $D_{\min}$ in every image. Then, the actual maximum diameter and minimum diameter is calculated by calibration. If the shape is round, pearl's size will be represented by minimum diameter $D_{\min}$, otherwise, it will be represented by $D_{\max} \times D_{\min}$.

7. EXPERIMENTAL RESULTS

7.1 The Experiment of Lighting Source

In order to test and verify the pearl's entire surface image captured by the device designed in this paper, we developed a simple prototype of detection device, as Fig. 6 shows. According to Fig. 7, the images of five viewpoints could effectively capture the pearl's whole surface. And in order to make the blemish, spot, color which reflects pearl's quality distinct and visible, we did many researches on lighting design. It can be divided into top light source, side light source and bottom light source, the experimental image is shown in Fig. 8. According to the results, each kind of LED lighting has its own advantages and disadvantages: (1) Advantages of top light source: The color of pearl in image is the most real in the three kinds of LED lighting, and it is beneficial to detecting large blemish. Furthermore, it is easy to put a LED on the top of the device. Disadvantages of top light source: There is a highlight area in each image that will affect blemish detection. Besides, it is also difficult to distinguish small blemish, as shown in Fig. 8(c). (2) Advantages of bottom light source: No highlight area, easy to structure device and blemish will be obvious under an appropriate intensity of light. Disadvantages of bottom light source: As for pearls with different color, it needs different intensity of light. In addition, different light intensity will cause remarkable effect on image's color and influence color judgment, as Fig. 8(a) shows. (3) Advantages of side light source: Compared to top light source, blemish will be more obvious. And device can utilize constant light intensity to shoot pearl has different color. Disadvantage of side light source: There is a huge difference between the pearl's color in image and the human eyes observed, as Fig. 8(b) shows. Besides, the highlight area will affect blemish detection just like top light source.

According to the experiment results, we placed a hemispherical LED near the camera to provide top light source in this paper.

Fig. 6 Detection device prototype of monocular multi-view stereo vision

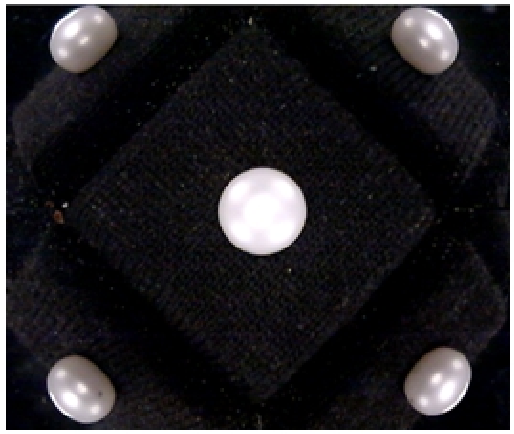

Fig. 7. Five perspective pearl image obtained by the monocular multi-view stereo vision detection device

a) Bottom light source b) Side light source c) Top light source

Fig. 8. Pearl images in the light of different position

7.2 The Experiment of Pearl's Size and Shape Detection

Fig. 9 shows five perspective pearl images cut apart by Ostu algorithm, and Fig. 10 is their edge images after edge detection. From these two figures, we can obtain pearl's shape information clearly.

In order to verify the accuracy and instantaneity of the algorithm, this paper utilized some pearls which were classified by professional person to conduct an experiment. The first experiment utilized classified pearls and the result was shown in table 1. Second experiment utilized pearls without classified and the result was shown in table 2. Experimental results showed that the average identification rate of pearl's shape reached 87.5%, and the processing time was 375ms. Document [6] gave the result that their identification rate was 80%, lower than this paper. And the processing time in document [7] which used four cameras was 333ms. In this paper, we just use one camera and the processing time is almost same as their research. As a whole, both the speed and accuracy in this paper have reached the real time requirement.

Fig. 9. Five perspective pearl image cut apart by Ostu

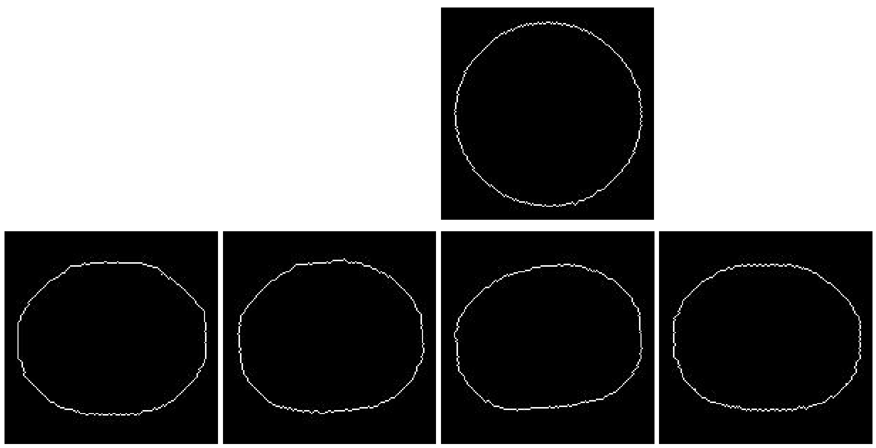

Fig. 10. Five perspective pearl edge image obtained by the edge extraction

The recognition results of pearl's size were based on the national standard. If the pearl's shape is round, use the minimum diameter $D_{\min}$ to represent the recognition result. Otherwise, use $D_{\min} \times D_{\max}$ to represent the recognition result. Through the experiment, we found that the size error is below 1%.

Table 1. Pearl shape recognition experiment results (classified)

Pearl's shape	Artificial identification number	Compute r identification number	Misjudgment number	Misjudgment rate
Round	8	6	2	25%
Ellipse	8	7	1	12.5%
Flat-head	8	7	1	12.5%
Sharp-head	8	8	0	0%

Table 2. Pearl shape recognition experiment results (no classified)

Pearl's shape	Artificial identification number	Computer identification number	Identification rate
Round	8	6	
Ellipse	8	10	
Flat-head	8	10	87.5%
Sharp-head	8	6	

8. CONCLUSION AND PROSPECTION

In recent years, the panoramic imaging technology which takes the object as the center is one of the important issues in machine vision field. In this paper, a detection device of panoramic machine vision using the monocular multi-view imaging technology, which possesses unified color system and camera internal parameters, is designed for pearl's detecting and grading. It provides a technical support on automatic, accurate and rapid grading of pearls. With the 5 threads' image processing, the pearl's quality indicators such as size, shape, luster, blemish and color could be detected in parallel. With the using of relatively closed detecting shell and appropriate light, the device could effectively reduce the interference of environment ambiguity and pearl surface's reflection.

In this paper, the pearl's detecting and grading device based on monocular multi-view machine vision mainly has benefits on: 1) Monocular multi-view is able to capture five different images of pearl's surface. This method enormously simplifies the complexity of automatic detection device based on machine vision and reduces the cost of device. Besides it also provides convenience of subsequent image analysis and processing. 2) The pearl image's analyzing and processing follows the national grading standard.

The future research is mainly about the following aspects: 1) Develop a monocular single-view panoramic imaging technology to satisfy various requirement of detection technology. 2) Improve the algorithm's accuracy, robustness and instantaneity of pearl's detecting and identification. 3) Perfect the knowledge database, image identification's algorithm database and variety of detection index database, and it will provide data support for improving the accuracy in pearl's detecting and grading.

CONSENT

Written informed consent was obtained from the participants.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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