Extraction Method of Scallop Area from Sand Seabed Images

Koichiro ENOMOTO†(a), Student Member, Masashi TODA††(b), Member, and Yasuhiro KUWAHARA†††, Nonmember

SUMMARY The results of fishery investigations are used to estimate the catch size, times fish are caught, and future stock in the fish culture industry. In Tokoro, Japan, scallop farms are located on gravel and sand seabed. Seabed images are necessary to visually estimate the number of scallops of a particular farm. However, there is no automatic technology for measuring resources quantities and so the current investigation technique is the manual measurement by experts. We propose a method to extract scallop areas from images of sand seabed. In the sand field, we can see only the shelly rim because the scallop is covered with sand and opens and closes its shell while it is alive and breathing. We propose a method to extract the shelly rim areas under varying illumination, extract the scallop areas using the shelly rims based on professional knowledge of the sand field, explain the results, and evaluate the method’s effectiveness.

key words: scallop, fishery resource investigation, automatic counting, image processing

1. Introduction

The fish culture industry is planning to fisheries investigate resources. Each relevant organization conducts various fishery investigations and collects data [1]–[3]. The results of investigations are used to estimate the catch size, times fish are caught, and future stocks [4]. Therefore, the fishing industry is under increasing pressure to accurately estimate fishery resources of the number, size, and states.

Recently, investigation methods have been developed to measure fishes using still images or video from an underwater camera [1], [2]. These methods can be used to investigate benthic fishery resources, but an acoustic survey cannot be used due to inadequate resolution [5]. However, these methods do not use automatic measurements from an underwater camera [1]–[3], [6]. In biology and ecology, Bassett et al. investigated nocturnal fish populations using baited underwater video, but this investigation involved manual measurement [6]. In computer vision, Aguzzi et al. proposed a method to implement new automated image analysis protocols to determine and count benthic decapods using Scale-Invariant Feature Transform (SIFT) features and Fourier descriptors, and showed the method’s effectiveness [7]. However, this method cannot be adapted for other fishes and shellfish because it does not use biological or ecological features, or take into account other seabed environments such as gravel and ballast.

In the scallop culture industry [8] in Abashiri, Japan, sea life is investigated by analyzing the seabed images [3]. The scallop habitat is gravel and sand seabed [9]. The seabed images are now obtainable from catamaran technology. However, there is no automatic technology for measuring the data from these images, so the current investigation technique involves manual measurement by experts [5]. Automatic methods must be developed to measure scallop beds more quickly and investigate fisheries more accurately.

Our aim was to develop an automatic method for measuring the number, size, and states of scallops. We have already proposed a method to extract the scallop areas using scallop features, such as color, fluted patterns, and fan-like shapes, from gravel seabed images [5]. We have shown that the extraction rate accuracy was 95%. However, this method cannot be adapted to images of sand fields, because scallops are covered with sand. In the fishing grounds off of Tokoro, Japan, the distribution of the bottom sediments includes fields of gravel, granules, fine sand, and sand [10]–[13]. Fields of gravel and granules have high population densities of scallops, and sand fields have lower population densities [10]. In sand fields, seeded images should cover a wider area and be more accurate because the scallop population density is low. Therefore, automatic methods must be adapted to extract scallop in sand fields.

Environments to be photographed have a high degree of noise, including large differences in lighting [5]. The images also include gravel, sand, clay, and debris. In sand fields, scallops are covered with sand. However, the scallops’ shelly rims are not. We propose a method to extract the scallop areas using professional knowledge from images of sand seabed, explain the results, and evaluate the method’s effectiveness.

The next section describes seabed images and design considerations for extracting of scallop areas from seabed images. We explain the preparation methods of seabed images in Chapter 3 and describe the details of scallop features.
defined to extract scallop areas in Chapter 4. We explain the experimental method and results obtained from applying our method to seabed images and discuss the effectiveness of our method in Chapter 5.

2. Design Consideration

2.1 Shooting Procedure of Seabed Image

The method of capturing seabed images is based on professional knowledge and ecology. Figure 1 shows a simplified schematic of the photography environment. Fishery investigations involve counting scallops in $1m \times 1m$ areas. The photography equipment is a metallic frame, a digital camera, lighting, and a switch. Figure 2 shows the process of capturing seabed images. The lighting remains off until just before shooting because changes in lighting cause scallops to move away. First, the photography environment is sunk from the catamaran at the investigation point (Fig. 2 (a)). The camera captures an image when the switch touches the seabed (Fig. 2 (b)). Therefore, the seabed images capture scallops but not turbidity.

The seabed images have problems such as capturing the metallic frame of the camera apparatus in the photograph which affects image processing of scallop areas [5]. Moreover, the seabed images greatly differ in lighting, because they are taken for measurement by experts. Therefore, seabed images are not lit well enough for the image processing. We describe the solution to these problems in Sect. 2.2.

2.2 Proposed Method

Figure 3 shows a digital photograph of a sand seabed (1536×1024 pixels in 24-bit color). This seabed image contains scallops, sand, and shell debris. The size of the scallops can be determined because if we have information about the target area, we can determine the age of the scallops.

The seabed images differ in lighting and the metallic frame is photographed because of the shooting process (Sect. 2.1). Moreover, in sand fields, the sand areas of an image have a high degree of noise. These problems are processed in the preparation (Sect. 3) such as the image smoothing (Sect. 3.1) and the removing of the metallic frame (Sect. 3.2) and the dark areas (Sect. 3.3).

Figure 4 shows a scallop area of $64 \times 64$ pixels in sand and gravel fields. In the sand field (Figs. 4 (a) and (b)), the scallop areas have special features such as white fan-shaped shelly rims. However, in gravel field (Fig. 4 (c)), the scallop features are fluted patterns, colored shells, and fan-like shapes [5]. In sand fields, there is usually no sand on the shelly rim due to the scallops opening and closing their shells while alive and breathing. For the same reason, the scallops do not overlap each other. In the seabed images, the shadow information cannot be used, because it includes uneven sand surface and noise. These facts are based on knowledge of ecologists and fishermen.

Figure 5 shows our proposed method to extract the scallop areas in sand fields. First, in preparation, the seabed images are smoothed using Mean-Shift filtering (Sect. 3.1) and the metallic frame area (Sect. 3.2) and the dark areas (Sect. 3.3) are removed. The candidate shelly rim pixels are extracted from the obtained image by dynamic threshold processing (Sect. 4.1). Next, the candidate scallop area is extracted using the Hough transform (Sect. 4.3). Finally, the scallop areas are extracted by threshold processing using shelly rim features (Sect. 4.4).

3. Preparation

3.1 Image Smoothing

The object image must be smoothed without losing detail of scallop features because the background of the object image
is a noisy sand area. Therefore, we compared smoothing methods such as Mean-Shift, Median, and Gaussian filtering.

Mean-Shift filtering is a smoothing method for edge-preserving smoothing [14]. Here, $s$ and $r$ denote the spatial and range components of a vector, respectively. The kernel bandwidths are denoted as $(h_s, h_r)$. Here, in this paper, we empirically set $(h_s, h_r) = (20, 15)$. Median filtering is a sliding-window spatial filter, but it replaces the center value in the window with the median of all the pixel values in the window. In this paper, we use the median filtering of a single $3 \times 3$ window of values. Gaussian filtering is selected according to the shape of the Gaussian function to the weights of the linear smoothing filter. In this paper, we use Gaussian filtering of a single $3 \times 3$ window.

Figure 6 shows the results of smoothing using Mean-Shift, Median, and Gaussian filtering in images of scallops. The sand areas were smoothed without losing detail in the scallop areas with Mean-Shift filtering (Figs. 6(b1)–(b3)) but the shelly rim areas were smoothed using Median filtering and Gaussian filtering (Figs. 6(c1)–(c3) and (d1)–(d3)). Therefore, we used Mean-Shift filtering. Figure 7 shows the results from smoothing seabed image.

### 3.2 Removal of Metallic Frame

The seabed image includes the metallic frame of the apparatus. The metallic frame has a striped pattern of light blue and black, and the area is reflected by the photoflash. Therefore, the metallic frame must be removed by template matching.

Figure 8 shows the templates for template matching. The template images are selected manually from a part of...
the metallic frame. Figure 8 (a) shows part of the top center of the metallic frame, and Fig. 8 (b) of the middle. In the template images, the white areas are not compared with the object image. The match metrics of template matching are the sum of squared differences (SSD) in the RGB color space.

In a seabed image, the metallic frame size is almost constant. Therefore, we can calculate the coordinate of the metallic frame by the coordinates of two parts of the metallic frame obtained using template matching. The metallic frame is removed using this information.

3.3 Recognizable Areas

Seabed images greatly differ in lighting due to the photography equipment. Therefore, it is difficult to recognize the color and shape in the dark parts of these images when modeling scallop features [5]. Our method defines the recognizable areas and removes unrecognizable areas.

A recognizable area is defined as follows. The image \( I \) of size \((M, N)\) and localized region \( I_{local} \) of size \((W, H)\) in image \( I \) are denoted as \( I_{local} \subset I \). Localized region \( I_{local} \) is defined as a recognizable area when the mean of pixel values \( \mu_I \) of localized region \( I_{local} \) satisfies threshold \( TH_L \leq \mu_I \). This process is done on a whole image \( I \) on moving bandwidth \( k \) of localized region \( I_{local} \). In this paper, we set the localized region size for a scallop as \((W, H) = (64, 64)\), moving bandwidth \( k = 16 \), and threshold \( TH_L = 75 \).

Figure 9 shows the results of the removed frame and extracted recognizable area. The metallic frame and dark areas were removed from the seabed image. The extracted area was also well lit well. In this paper, we used images of recognizable areas obtained in this way and analyzed the extracted areas.

4. Modeling of Scallop Features

4.1 Shelly Rim Candidate

In sand fields, the scallop’s shelly rim is sight because moving the scallop’s shell (Fig. 4 (a), (b)). Scallop’s shelly rims are generally white. We define the color based on the rim’s whiteness.

The candidate pixels of a shelly rim are defined by the high lightness values in the local areas. However, it is difficult to extract shelly rim areas using static threshold processing because seabed images greatly differ in lighting. We describe a method for extracting shelly rim areas using dynamic threshold.

4.1.1 Dynamic Threshold Processing

Image \( I \) and localized region \( I_{local} ' \) of size \((W', H')\) in Image \( I \) are denoted as \( I_{local} \subset I \). Even if the localized region \( I_{local} ' \) is large enough, the rate of the shelly rim pixels will be low. This is because the localized region \( I_{local} \) includes mostly sand areas (Fig. 4 (a), (b)). In the localized region \( I_{local} ' \), the shelly rim pixels have a high lightness value because the scallop’s shelly rim is white.

The candidate pixels of a shelly rim \( SR_c \) are defined as follows on the basis of these features. A lightness histogram is obtained for the localized region \( I_{local} \). When the central coordinate of the localized region \( I_{local} \) is \((x_0', y_0')\), the threshold of a candidate of a shelly rim \( TH_{SR}(x_0', y_0') \) is defined as

\[
TH_{SR}(x_0', y_0') = L_{ar} + \lambda L_{ar} ',
\]

where \( L_{ar} \) is the average lightness and \( L_{ar} ' \) is the standard deviation. Also, \( \lambda \) is set by the rate \( p \) of a candidate pixel of the shelly rim when the histogram is assumed to have a normal distribution. If threshold \( TH_{SR} \) is higher than \( TH_{SR_{ave}} \), we define it as \( TH_{SR} = TH_{SR_{ave}} \), because the lightness value is limited. This threshold \( TH_{SR}(x_0', y_0') \) is the threshold of \( I(x, y) \) when the coordinates of image \( I \) corresponding to \((x_0', y_0')\) is \((x, y)\). This process involves the whole image \( I \) on moving bandwidth \( k' \) of the localized region \( I_{local} ' \). A whole image of threshold \( TH_{SR} \) is calculated using a linear interpolation method. A pixel of image \( I(x, y) \) is defined as a candidate pixel of the shelly rim \( SR_c \), when \( I(x, y) \) satisfies

\[
TH_{SR}(x, y) \leq I(x, y).
\]

4.1.2 Preliminary Experiment and Results

We examined the localized region parameters \((W', H')\), and
Table 1 Comparison results of localized region parameters \((W', H')\).

| Parameters \((W', H')\) | Shelly rim pixels | Other pixels | Extraction rate \(E\) |
|-------------------------|-------------------|--------------|----------------------|
| (32, 32)                | 142               | 1578         | 0.083                |
| (64, 64)                | 169               | 1612         | 0.095                |
| (128, 128)              | 124               | 2232         | 0.053                |
| (256, 256)              | 91                | 2126         | 0.041                |

Fig. 10 Lightness histogram and threshold \(Th_{SR}\) of object images. Object images are those in Figs. 4 (a) and (b).

Fig. 11 Results of threshold \(Th_{SR}\) in seabed image. Object image is that in Fig. 7.

Fig. 12 Results of candidate pixels of shelly rim. Object image is that in Fig. 7. White pixels are candidate pixels of shelly rim.

Fig. 13 Results of the candidate pixels of shelly rim in the scallop area. The object images are Fig. 4 (a) and (b).

selected their optimum values to extract shelly rim pixels.

The extracted area of the shelly rim pixels is denoted as \(S_{rim}\), and the area of all the extracted pixels is denoted as \(S_{total}\).

Here, the extraction rate \(E_{(W', H')}\) is defined as

\[
E_{(W', H')} = \frac{S_{rim}(W', H')}{S_{total}(W', H')}.
\]

(3)

We used a clipped seabed image of \(400 \times 400\) containing two scallops. Parameters \((W', H')\) were set as \((32, 32)\), \((64, 64)\), \((128, 128)\), and \((256, 256)\), and the moving bandwidth was set as \(k' = 16\), \(Th_{SR_{upper}} = 245\), the rate of the shelly rim \(p = 0.01\), and \(\lambda\) is given as \(2.326\).

Table 1 compares the results of the localized region parameters \((W', H')\). In Table 1, the shelly rim pixels and the extraction rate \(E\) were best when the parameter \((W', H')\) were \((64, 64)\), but the extracted pixels covered the most area when the parameters \((W', H')\) were \((128, 128)\). In this paper, we set \((W', H') = (64, 64)\).

Figures 10 and 11 show the results of the lightness histogram and the map of threshold \(Th_{SR}\), respectively. Figures 12 and 13 show the results of extracting the candidate pixels of a shelly rim. The threshold \(Th_{SR}\) was adapted to change according to the lightness of the localized regions (Fig. 10–13).
4.2 Scallop Shell Shape

The scallop’s shell is shaped like a fan. We define the shape of the scallop shell as an ellipse and extract it using the Hough transform to detect ellipses. This method is effective against noise and can be set at arbitrary sizes. Moreover, we can estimate the actual size of the scallop from its results. The feature points used are described in the following section. An ellipse is defined as

\[ f(x, y, \alpha, \beta, \phi) \]

by five parameters (Fig. 14): the center point \((x_0, y_0)\), two semi-axes \((\alpha, \beta)\), and an orientation \(\phi\). These parameters are determined by voting in the Hough parameter space. The extracted ellipses are the candidates for the scallop areas. Since the scallop areas have a constant range of sizes (Sect. 2.2), we can set the two semi-axes at \(22 \leq \alpha, \beta \leq 36\), and the ellipticity \(\beta/\alpha\) at \(0.85 \leq \beta/\alpha\). In this paper, the orientation parameter is set at \(\phi = 0\) to increase calculation speed because the shape of a shelly rim is less than half an ellipse (Fig. 4).

4.3 Integration of Shelly Rim and Shape Features

As mentioned above, a scallop’s shell is fan-like, and the shelly rim is white. Therefore, if the pixels are a scallop’s shelly rim, the candidate pixels follow the scallop’s rim. We define the candidate pixels of the shelly rim as the feature points for the Hough transform. Suppose \(C\) denotes a set of all detected candidate pixels (Sect. 4.1.1) and \(c\) denotes a candidate pixel as \(c \in C\). By applying Hough transform on all candidate pixels \(c \in C\), we obtain an ellipse that fits \(c\) as much as possible.

Figure 15 shows the relationship between an ellipse extracted using the Hough transform and the parameter space. Here, \(\Delta\alpha\) and \(\Delta\beta\) denote the resolutions of the parameter space. When \(Q\) denotes the near region of this elliptic boundary \(f(x, y, \alpha, \beta)\) has the feature points that are voted. Region \(Q\) is expressed

\[ f(x, y, \alpha - \frac{\Delta\alpha}{2}, \beta - \frac{\Delta\beta}{2}) \leq Q \leq f(x, y, \alpha + \frac{\Delta\alpha}{2}, \beta + \frac{\Delta\beta}{2}). \] (4)

In Fig. 15, \(Q\) is the gray regions. In the parameter space, the number of voting pixels is the same as that of the feature points on \(\bar{Q}\), because the feature points are voted the corresponding parameter space. In this paper, we set \(\Delta\alpha, \Delta\beta = 2\) because the line widths of a shelly rim are one pixel.

4.4 Definition of Scallop Area

This section describes how features of scallop areas are determined by the shelly rim and shape. Some sand fields contain granules, fine sand, and sand. Therefore, the candidate pixels of a shelly rim vary in their distribution in some states.

Figure 16 shows the distribution of the candidate pixels of a shelly rim on the extracted ellipse described in Sect. 4.3. There was a high possibility that the scallop area would be contained in the image shown in Fig. 16 (a) and the noise area in Fig. 16 (b). Moreover, the candidate pixels should be low in the scallop area without a shelly rim, because the scallop is covered with sand. Therefore, we defined the value of a shelly rim using the number of candidate pixels.

We defined the boundary length of the ellipse \(l\) and the parameter \(D\) (\(1 \leq D\)). The length of an arc is expressed as \(\frac{1}{D}l\). In the range of \(\frac{1}{D}l\), the maximum number of feature points on a region \(Q\) is calculated, and denoted as \(Num_Q\). Here, the value of the shelly rim feature \(R_Q\) is defined as

\[ R_Q = \frac{Num_Q}{\frac{1}{D}l}. \] (5)

In the candidate area \(P\), the region inside \(Q\) is denoted as \(\bar{Q}\). The number of candidate pixels on \(\bar{Q}\) is calculated, and denoted as \(Num_{\bar{Q}}\). Here, the rate \(R_{\bar{Q}}\) is defined as

\[ R_{\bar{Q}} = \frac{Num_{\bar{Q}}}{\bar{Q}}. \] (6)
We defined the scallop areas when $R_Q$ and $R\bar{Q}$ satisfy

$$Th_Q \leq R_Q \cap R\bar{Q} \leq Th_{\bar{Q}}$$  \hspace{1cm} (7)

where $Th_Q$ is the threshold for the shelly rim feature $R_Q$ and $Th_{\bar{Q}}$ is the threshold for the inside a shelly rim feature $R\bar{Q}$. Equation (7) is a condition for the scallop area.

5. Experiment

5.1 Preliminary Experiment

5.1.1 Method

We examined the parameters $D$ and $Th_Q$ to set the optimum values. We used 19 seabed images containing 79 scallops in this experiment. The 19 seabed images contained 72 scallops that were clearly visible and had enough shelly rim area to extract. Scallops having a white shelly rim an eighth of the boundary length of the ellipse $l$, is defined as “clear” because we cannot determine whether an area is a scallop area or debris if the white area is small.

The evaluation methods are defined as follow. If a scallop area was extracted correctly in all extracted areas, we determined the results to be true-positive (TP). If the scallop area was not extracted, we determined the results to be true-negative (TN). Furthermore, if a non-scallop area was extracted incorrectly, we determined the results to be false-positive (FP). The number of the scallops is denoted as $N_{	ext{scallop}}$. The extraction and error rates are defined as

$$\text{Extraction rate} = \frac{TP}{N_{	ext{scallop}}},$$  \hspace{1cm} (8)

$$\text{Error rate} = \frac{FP}{TP + FP}.$$  \hspace{1cm} (9)

Parameter $D$ is changed to $D = 2$, $D = 4$, and $D = 8$. The threshold for the shelly rim feature $Th_Q$ is changed every 0.1 on 0.1–1.0. We set $Th_{\bar{Q}} = 0.03$ in a sand field.

5.1.2 Results

The preliminary experimental results of extraction and error rates are shown in Figs. 17 and 18.

When $D = 8$, the error rate of all scallops and “clear” scallops was higher than 22.7% (Fig.18), though the extraction rate accuracy was higher than other parameters (Fig.17). When $D = 2$, no areas were half the boundary length of $l$ (Fig. 17 (a): $Th_Q = 1.0$). Moreover, the extraction rate accuracy of all scallops and “clear” scallops was lower than others.

Parameter $D = 4$ is the optimum value, because the shelly rim feature is reflected in Fig. 17 and the error rate was stability transition while $0.6 \leq Th_Q$. The extraction rate accuracy for “clear” scallops was 90.3% and the error rate was 18.8% when $Th_Q = 0.6$. The method was accurate enough and comparable to the extraction method for gravel seabed images [5].

5.2 Experiment

5.2.1 Method

In this experiment, we used 25 seabed images containing 87 scallops and the parameters discussed in Sect. 5.1. Seventy were “clear” scallops. The evaluation method is the same as that discussed in Sect. 5.1.

5.2.2 Results

Samples the experimental results are shown in Figs. 19 and 20. In Fig. 19, 5 “clear” and 3 were unclear, and all “clear” scallops were extracted correctly. The value of the shelly rim feature $R_Q$ was adapted to the variance of the candidate pixels of the shelly rim. The scallop area of Fig. 20 (c) was extracted correctly using the proposed method, but the scallop areas of Figs. 20 (a) and (b) were not extracted. The non-scallop area of Fig. 20 (d) was not extracted correctly when the experiment involved the shelly rim feature $R_Q$. In Fig. 20 (e), the white regions are shell debris. The non-scallop area of Fig. 20 (e) was not extracted incorrectly when the experiment involved the inside of a shelly rim feature $R_{\bar{Q}}$.

All experimental results are listed in Table 2. The extraction rate accuracy of the scallop areas was 73.6%, and the extraction rate accuracy of “clear” scallops was 91.4%.
Fig. 18 Preliminary experimental results of error rate. (a) Results of all scallops. (b) Results of “clear” scallops.

Fig. 19 Sample of experimental results. Object image is that in Fig. 3.

Table 2 Experimental results.

| No. of scallops | TP | FP | Extraction rate | Error rate |
|-----------------|----|----|-----------------|------------|
| all             | 87 | 64 | 73.6%           | 17.9%      |
| clear           | 70 | 64 | 91.4%           | 17.9%      |

5.3 Discussion

We developed a method to extract the scallop areas from sand seabed images using the shape and color of the shelly rim. If the feature points for the Hough transform are the edges points, they included the edges of shadow, sand, and debris. Therefore, the scallop areas cannot be extracted correctly using only the edges of the scallop shape. The proposed method defines the feature points as candidates for shelly rim pixels, the shelly rim, and the inside of a shell. The scallop area can not be extracted correctly using only the shape feature in a sand field. The proposed method could extract scallop areas because the candidates of the shelly rim were widely distributed. In Fig. 20 (e), the non-scallop area was not extracted correctly because but the shell debris was white and covered with sand like a scallop.

There were also false-positive cases, although the extraction rate accuracy was high enough to measure the scallop. The error rate was 17.9%. This method is accurate enough and comparable to the extraction method for gravel seabed images [5].

The extraction rate manual measurement is said to be 95%. The extraction rate of “clear” scallops was 91.4% (Table 2) with the proposed method. These results are sufficiently accurate.

6. Conclusion

This paper has presented a method to extract the state of scallop beds from sand seabed images. The photography environments of the seabed image have a high degree of noise; for example, large differences in lighting, sand, debris, and the metallic frame used to take the seabed images. This method smooths images and removes the metallic frame and removes unrecognizable areas. In sand seabed images, we cannot see most of the scallop areas because scallops are covered with sand. This method defined the features of the scallops by using the color and shape of the shelly rims, and modeled them on the basis of professional knowledge. The method extracts scallop areas using these model features. Additionally, the experimental results showed that our method is effective.
For future work, we will investigate a method for extracting the scallop areas from ballas, such as mixed sand and gravel fields to produce videos for fishery investigations.

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