A wave matching method in infrared image for 3-D wave measurement

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Abstract: *We uses binocular stereo vision infrared cameras to measure the height of the waves for tsunami warning. The characteristic of infrared camera is to use the difference in temperature and emissivity between target and background that causes infrared images to have low signal-to-noise ratio and blurring of waves. This will affect the accuracy of the wave matching. In this paper, we propose a new method of wave matching to improve the accuracy of matching. The sea waves are divided by several lines, and the distance between each line and the sea waves is the characteristic vector of the waves, and the matching sea waves are judged by comparing the similarity of the characteristic vectors. The final calculated wave height is consistent with the official data trend.*

Keywords: binocular stereo vision, infrared camera, wave matching, characteristic vector, image processing.

1. Introduction

Our laboratory is developing a tsunami warning system based on sea wave measurements. In order to observing the sea all day, according to the theory of binocular stereo vision, we set up two infrared cameras on land to monitor the sea surface and to measure the height of waves. However the shortcomings of the infrared (IR) camera are obvious. Compared with the visible camera, because of the smaller focal length of the infrared camera, the wave is small and the characteristics of the wave are not obvious [1], which brings great difficulty for the matching of the waves. Figure 1 is the wave extracted image from the IR image.

(a) Original image (b) Enlarge image (c) Extracted image

Fig. 1. The wave extracted image

General matching methods including based on feature matching, SIFT algorithm matching, etc. Based on feature matching [2] is to calculate the area, circumference and curvature of each wave, and take these features as the characteristic vectors of the waves, compare them with the characteristic vectors of the waves in the left and right image. Because of the small waves of IR image and the different angle of view of camera, the parameters of the vectors are greatly affected. The SIFT algorithm [3] matching requires enough textures for the image. The infrared image of the waves almost no texture, so the SIFT algorithm is completely ineffective.

In order to solve the problem of wave matching in IR images, a new method named Straight Line Intersection is proposed to describe the characteristics of sea waves. This method defines a certain number of lines that intersect with the waves, and record the distance between the lines and the waves as the parameter of the Wave vector. Then the corresponding matching points of the waves are judged by comparing the similarity of the vectors.

2. Methods

2.1 Based on feature matching

In the process based on feature matching, first we take the characteristics of each wave as a vector. The vector is composed of size s, circumference l, curvature r, etc. Formula (1) is a vector $\boldsymbol{T}$ on a wave. Then we compute the vector of all the waves in the left and right images. $\boldsymbol{T}_{\mathrm{L}}, \boldsymbol{T}_{\mathrm{R}}$ represent the vector of all waves on the left and right image as shown in formula (2), N and M indicate that there are N and M waves on the left and right image.

$$\boldsymbol{T} = [s, l, r] \tag{1}$$

$$\boldsymbol{T}_{\mathrm{L}} = \begin{bmatrix} \boldsymbol{T}_{\mathrm{L}1} \\ \boldsymbol{T}_{\mathrm{L}2} \\ \cdots \\ \boldsymbol{T}_{\mathrm{L}i} \\ \cdots \\ \boldsymbol{T}_{\mathrm{L}(N-1)} \\ \boldsymbol{T}_{\mathrm{L}N} \end{bmatrix}, \quad \boldsymbol{T}_{\mathrm{R}} = \begin{bmatrix} \boldsymbol{T}_{\mathrm{R}1} \\ \boldsymbol{T}_{\mathrm{R}2} \\ \cdots \\ \boldsymbol{T}_{\mathrm{R}j} \\ \cdots \\ \boldsymbol{T}_{\mathrm{R}(M-1)} \\ \boldsymbol{T}_{\mathrm{R}M} \end{bmatrix} \tag{2}$$

The vector of each wave $\boldsymbol{T}_{\mathrm{L}i}$ on the left image compare with all the vector of waves on the right image, which is the corresponding matching point of i when the similar value (Sim) is the lowest at each j values. The similar value (Sim) is calculated by formula (3).

$$\mathrm{Sim}(i, j) = \frac{\boldsymbol{T}_{\mathrm{L}i} \cdot \boldsymbol{T}_{\mathrm{R}j}^{T}}{\|\boldsymbol{T}_{\mathrm{L}i}\| \cdot \|\boldsymbol{T}_{\mathrm{R}j}\|} \tag{3}$$

The advantage of this method is that the parameters of the vector are less and the calculation speed is faster. However, there are two problems with this matching parameter.

(1) The problem of similar shapes

Figure 2 shows an example of problem of similar shapes. (a) is the wave that needs matching, and figure (b) and (c) are its candidate corresponding matching waves with different waves, then (b) is actual matching and (c) false matching. However, due to the similar shape and size of waves (b) and (c), then these parameters will lead to a false match.

(a) Left wave (b) Actual right wave (c) False right wave

Fig. 2. The problem of similar shapes

(2) The problem of crack shapes

Figure 3 shows an example of problem of crack shapes. (a) is the wave that needs matching, and (b) is its actual corresponding matching wave. However, due to the different shooting angles and the influence of the wave extraction, the deformation of (b) will occur, and the parameters will also change greatly, so that the corresponding wave cannot be correctly found.

(a) Left wave (b) Actual right wave

Fig. 3. The problem of crack shapes

2.2 Straight Line Intersection method

To solve this problem, we proposed a new method named Straight Line Intersection to describe the characteristics of sea wave. Shown as Figure 4.

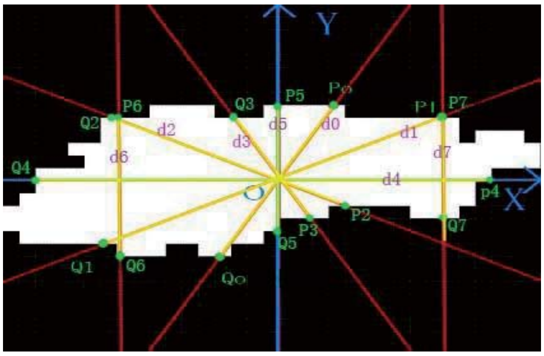


Fig. 4. The line intersects the waves

An axis is established with the center of gravity of the wave as the origin, the width of the waves is W and the height is H. And then we use L lines written as $f_i(x, y) = 0,\ (1 \leq i \leq L)$ to intersect the waves, the endpoints at the intersection are P_i and Q_i, d_i as the distance between P_i and Q_i and calculated by formula (4).

$$P_i(x_i, y_i)$$
$$Q_i(x_i', y_i') \tag{4}$$
$$d_i = \sqrt{(x_i - x_i')^2 + (y_i - y_i')^2}$$

We can obtain a new feature vector that describes the wave characteristics, shown as formula (5).

$$\boldsymbol{D} = [d_1, d_2, d_3, \dots, d_i, \dots, d_{L-1,} d_L] \tag{5}$$

Then we calculate the similarity of vectors by Euclidean distance (dist), shown as formula (6).

$$\text{dist} = \sqrt{\sum_{i=1}^{L} (d_{\text{L}i} - d_{\text{R}i})^2} \tag{6}$$

The method of finding the corresponding wave is the same as the feature-based matching we introduced in 2.1, except that the parameters of the vector are different. When the value of dist is the smallest, the two vectors are considered to be the most similar, that is the corresponding matching waves.

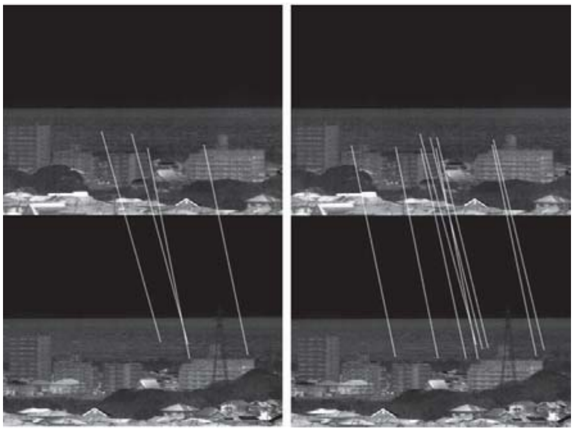
3. Experiments results

3.1 Matching result

We use horizontally configured binocular infrared camera to take pictures of the waves. The camera is about 3km away from the sea. And then L = 8 and $f_i(x, y)$ are using below:

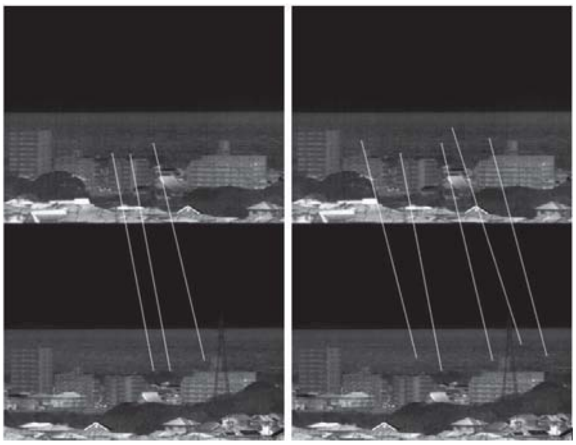
$f_1 : y - \tan 30^\circ x = 0$ $\quad f_2 : y - \tan 60^\circ x = 0$
$f_3 : y + \tan 30^\circ x = 0$ $\quad f_4 : y + \tan 60^\circ x = 0$
$f_5 : x + W/4 = 0$ $\quad f_6 : x - W/4 = 0$
$f_7 : x = 0$ $\quad f_8 : y = 0$

These 8 straight lines intersect with the waves. The characteristic vector of the wave has 8 parameters. The following Figure 5 and Figure 6 are the results of the wave matching.



(a) Previous method (b) Proposed method

Fig. 5. Match result comparison (1)



(a) Previous method (b) Proposed method

Fig. 6. Match result comparison (2)

The graph on the left is the result of based on feature matching method and the Straight Line Intersection method result is on the right. The upper part of the image is the left image, the lower part is the right image. The white line is the correspondence of the matched waves. We can see that the new method matches more waves than the previous method.

3.2 3-D wave measurement results

After the left and right waves are matched, the parallax can be obtained to calculate the three-dimensional coordinates (X, Y, Z) of the waves. The formula (7) is as follows. Where (x_1, y_1) and (x_2, y_2) is the location of wave in left and right images respectively, b is the distance between two cameras and f is the lens focal length, α and β are the angles of the left and right camera rotation.

$$X = \tan\left(\alpha - arctan\frac{x_1}{f}\right) \cdot Z$$
$$Y = \frac{Z \cdot y_1}{f} \quad (7)$$
$$Z = \frac{L}{\left|\tan\left(\alpha - \tan^{-1}\frac{x_1}{f}\right) + \tan\left(\beta - \tan^{-1}\frac{x_2}{f}\right)\right|}$$

We verify the correctness of the calculation by comparing the calculated Y data of the waves with the official tidal height measurement data. The figure 7 shows the wave height measurement data for a certain period of time. Shooting time is 5 seconds for a total of 150 photos. Calculate the height data of each matched wave in the photo to generate a coordinate system. The abscissa is the matched waves, and the ordinate is the value of the corresponding calculated Y.

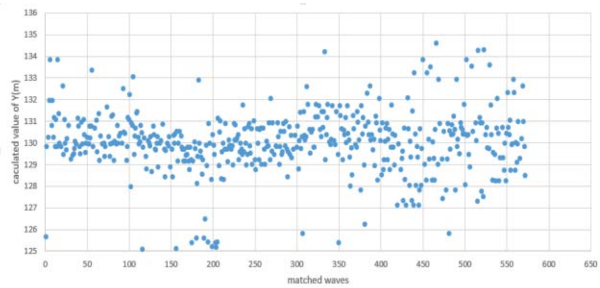


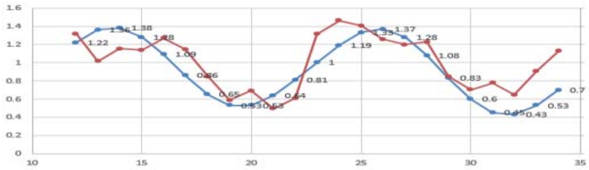
Fig. 7. Measurement results of waves height

Finally, we calculate the average value of Y at all points in this period to represent the height of the tide. As shown in the following formula (8). Y_i is the value of calculated waves height, N_{match} is the number of matched waves.

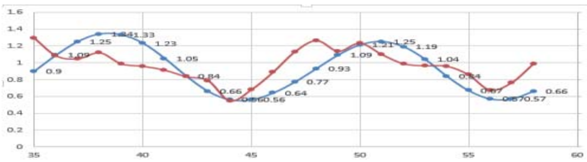
$$height = \frac{1}{N_{\mathrm{match}}} \sum_{i=1}^{N_{\mathrm{match}}} Y_i \quad (8)$$

Our experiment was based on 24 hours of data from match the waves in 150 photos per hour. Calculate the world coordinate of every point using by the trigonometric formula (7).

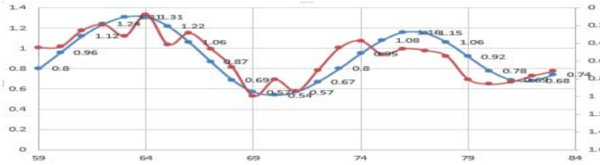
Then we compare with the experimental result and official tide data from Japan Meteorological Agency (JMA). Figure 8 shows the result of compare with the calculated result and official data, red line is calculated data, and blue line is official data.



(a)January 23,2018,weather:sunny,temperature:9°/2°



(b)January 24,2018,weather:foggy,temperature:2°/0°



(c)January 25,2018,weather:cloudy,temperature:5°/2°

Fig. 8. Compare with the measurement result and official data

In some hours calculated data and official data have a big error. There are two reasons for the following:(1)Sometimes the sea surface is calm and the matching waves are less, which has a great influence on the average calculation.(2) Sometimes the sea surface will produce white boundary lines similar to waves on infrared images due to different water depths, which will affect the matching results. However, we can see that the tendency of data we calculated is similar with the government information. So our proposed method can effectively measure the height of the waves.

4. Conclusion

Our purpose is use the binocular stereo vision cameras to analyze the wave images taken by infrared camera to measure the height of the waves. In order to reduce the error, we need to match as many waves as possible to calculate its height. Although our proposed method can measure the height of the waves, there are still matching errors and resulting in error between the calculated data and the actual data. Our next task is to reduce the error by extracting 20 to 200 points from an image, matching as many points as possible and reducing the time required for processing.

Reference

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