A Trial Toward Marine Watch System by Image Processing

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Abstract

This paper describes a marine watch system on a ship, which is aided by an image processing method. The system detects other ships through a navigational image sequence to prevent oversights, and it measures their bearings to maintain their movements. The proposed method is described, the detection techniques and measurement of bearings techniques are derived, and the results have been reported. The image is divided into small regions on the basis of the brightness value and then labeled. Each region is considered as a template. A template is assumed to be a ship. Then, the template is compared with frames in the original image after a selected time. A moving vector of the regions is calculated using an Excel table. Ships are detected using the characteristics of the moving vector. The video camera captures 30 frames per second. We segmented one frame into approximately 5000 regions; from these, approximately 100 regions are presumed to be ships and considered to be templates. Each template was compared with frames captured at 0.33 s or 0.66 s. In order to improve the accuracy, this interval was changed on the basis of the magnification of the video camera. Ships' bearings also need to be determined. The proposed method can measure the ships' bearings on the basis of three parameters: (1) the course of the own ship, (2) arrangement between the camera and hull, and (3) coordinates of the ships detected from the image. The course of the own ship can be obtained by using a gyrocompass. The camera axis is calibrated along a particular direction using a stable position on a bridge. The field of view of the video camera is measured from the size of a known structure on the hull in the image. Thus, ships' bearings can be calculated using these parameters.

Keywords: image processing, bearings measurement, navigation information system, navigational image sequence.

1. Introduction

According to the statistics released by the Japan Coast Guard, the number of ships involved in marine accidents in 2005 amounted to 2,482. The numbers of marine accidents classified according to ship type are listed in the descending order as follows: fishing vessel, 809; pleasure boat, 874; and cargo ship, 385. As observed from the list, medium or small-sized ships account for 75% of the total. When a comparison is made based on the cause of marine accidents, ship collisions are the most significant cause, followed by runs aground and engine problems. It is pointed out that approximately 75% or more of marine accidents are caused by human factors. Among them, insufficient lookout is the most significant cause [1]. In addition to radar and the automatic identification system (AIS), the Electronic Chart Display and Information System (ECDIS) has been applied widely in recent years [2]. The ECDIS displays the ship's own position and the electronic chart on the CRT screen. An extended ECDIS also displays information integrated with that provided by the automatic radar plotting aid (ARPA) and the AIS [3]. However, the method of identifying a small ship by radar usually requires fine tuning of the gain each time detection is conducted. Since domestic cargo ships that weigh below 500 GT have no duty to install the AIS, ships without the AIS cannot be detected [4]. Therefore, the conventional lookout by navigator is important to prevent small ships from causing marine accidents. As described above, insufficient lookout is a major cause of marine accidents. Under these circumstances, lookout support systems should be constructed and used extensively.

Safer navigation can be made possible if the movement of other ships can be monitored by image processing, which are not equipped with an AIS or cannot be detected by radar. Furthermore, the integration of the conventional navigation equipment and a lookout support system can help overcome certain shortcomings and capitalize on the advantages of each system.

This paper explains a method for detecting ships in a fluctuating environment. It also proposes a method for measuring the bearings of a detected ship from an image. Further, it evaluates the effectiveness of the proposed method by applying it to the image acquired by an experimental ship.

This paper is organized as follows: Section 2 describes the method for ship detection in a fluctuating environment; Section 3, method for measuring the bearings of a detected ship; Section 4, experiment; Section 5, experimental results; Section 6, discussion on data comparison between the image processing results and conventional navigation equipment; and Section 7, conclusion.

2. Method for ship detection in a fluctuating environment

Since the background image of a navigational image sequence is taken from a ship with fluctuating movement, the image changes with this fluctuation. Therefore, moving targets cannot be detected by the conventional background subtraction methods. Our previous ship detection method employs the characteristics of the transfer vector of each region transferred between frames and uses them as identification conditions [5], [6], [7], [8]. The period of movement fluctuation of a large and medium-sized ship is generally between several and ten-odd seconds. When a target detected in an image moves within a short interval of approximately 0.5s, its movement can be approximated by a straight line. Based on this feature, only a ship can be separately identified from the waves and backgrounds, even when the image is taken from a ship with fluctuating movement. Fig.1

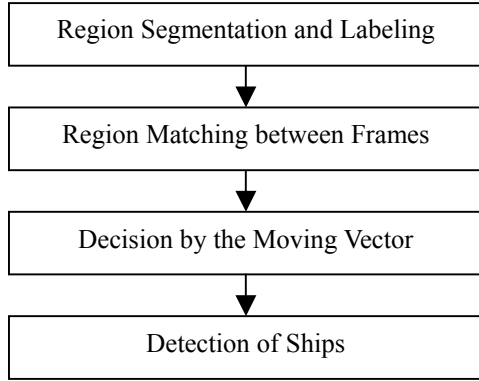shows a flowchart of the ship detection method.

Fig.1   Flow chart of detection method.

First, color images are transformed into brightness images with 256 grayscale levels. After region segmentation is performed on the entire image, labeling process is performed on each segmented region. The labeled regions on an image frame are matched with those on a frame generated at a short time interval later. The coordinates of each matched region are recorded in a data management table. Discrimination parameters are calculated from the transfer vector of each matched region by accessing the data management table. Formulas (1) through (5) represent for the calculation of the discrimination parameters, where x and y in (1), (2), and (5) are the coordinates of a region and subscripts 0, 1, and 2 refer to the original, first comparative, and second comparative images, respectively. The normal interval of image matching is 5 frames; this corresponds to approximately 0.16 s.

$$\textbf{\textit{MV1}} = (x_1-x_0, y_1-y_0)^t \tag{1}$$

$$\textbf{\textit{MV2}} = (x_2-x_0, y_2-y_0)^t \tag{2}$$

$$\text{Deflection} = |\, 2\textbf{\textit{MV1}}-\textbf{\textit{MV2}}\,| \tag{3}$$

$$\text{Speed} = |\,\textbf{\textit{MV2}}\,| \tag{4}$$

$$\text{Direction} = \arctan((y_2-y_0)/(x_2-x_0)) \tag{5}$$

The value of *deflection* in (3) represents the degree of straightness of the movement of a region. When two vectors— *MV1* and *MV2*—lie on the same line, the *deflection* is 0. The value of *speed* in (4) is the moving speed of a region. It corresponds to the value obtained from the image and is different from the moving speed on the sea. This is because it suffers from the disturbance caused by the fluctuation in the movement of the monitor's own ship. Since this fluctuation influences the entire image at the same speed, regions attributable to the same ship can be grouped by comparing and classifying the speed of each region.

The *deflection* is used for the identification of waves. When the waves do not move straight ahead, *deflection* attains a very high value. On the other hand, the *deflection* will decrease for regions attributable to ships or the background. In order to distinguish between a ship and background or between many ships, *speed* is used together with *deflection*. Since regions attributable to the same ship have the same speed vector, their values of *speed* are the identical. Since the background is a fixed target, its *speed* is lower than that of the ships. When there are many ships, multiple clusters of regions with the same *speed* are observed. These features are used as the discrimination criteria for the detection and selection of many ships.

3. Method for measuring the bearings of a detected ship

3.1 Obtaining the bearings

The information regarding both the "bearings" of any part in the image and the "viewing angle" of the entire image are necessary to measure the objective bearings from the image. The "bearings" of an image center can be determined once the bearings of the camera's shooting axis are obtained. However, complex equipment would be required since a camera and measurement equipment such as a compass must be connected mechanically. Since the camera has a zoom function that enables it to cover all the shooting areas from telephoto to wide angle, a feedback function for lens magnification (focal length) must be added to obtain a viewing angle.

It is preferable that no special function or mechanism be required to equip the ship with cameras, and a simple sets-up is desirable. It is also desirable to measure the bearings by only image processing with less exchange of information with other equipment. We propose a method to obtain the bearings of a ship using the following information: 1) the relative position of the camera and the ship, 2) the course of the experimental ship, and 3) the coordinates of the ship in the image.

3.2 Measurement of bearings

In this subsection, we describe a method for measuring the bearings of the specified index in the image. This method assumes that a part of the ship's structure for a specified index exists in the image.

The positional relationship between the position of the camera, specified index, and the axis of the experimental ship is measured. Fig.2 depicts the arrangement of the camera.
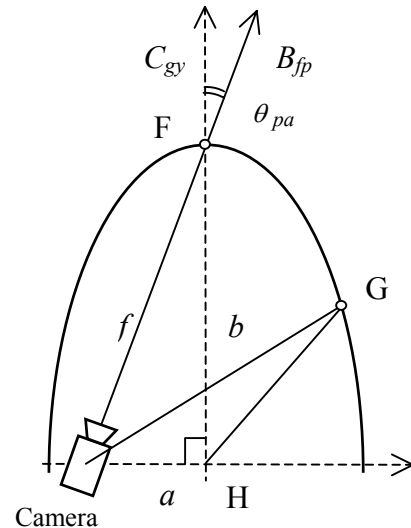

Fig. 2   Arrangement of the camera and the index of a hull (e.g. flag pole).

Fig.2 shows the bow of the ship. *"a"* represents the distance between the camera and H, which is the foot of the perpendicular from the camera to the ship's axis. *"b"* is the distance between the flag pole F on the bow as the specified index and H. *"f"* is the distance between the camera and F. Based on this relationship, the angle θ_{pa} between the bearings B_{fp} of the specified index shot by the camera and the experimental ship's course C_{gy} can be obtained from formula (6) using *"a"* and *"b"*. The point G where the ship's index is not located on the ship's axis can be obtained from formula (7) using *"a"*, *"b,"* and *"f"*.

$$\theta_{pa} = \arctan\left(\frac{a}{b}\right) \ [\text{deg}] \tag{6}$$

$$\theta_{pa} = 90 - \arccos\left(\frac{-b^2 + a^2 + f^2}{2af}\right) [\text{deg}] \tag{7}$$

The bearings B_{fp} of the specified index can be obtained from formula (8) using θ_{pa} and the experimental ship's course C_{gy}.

$$B_{fp} = C_{gy} + \theta_{pa} \tag{8}$$

When the camera is on the starboard side with respect to the specified index, we use formula (9) instead of (8).

$$B_{fp} = C_{gy} - \theta_{pa} \tag{9}$$

The bearings are in the range of 0° to 360°. If B_{fp} deviates the range, it is corrected using the following algorithm.

Algorithm 1
if $B_{fp} \geq 360$ then $B_{fp} = B_{fp} - 360$

else if $B_{fp} < 0$ then $B_{fp} = 360 - \left|B_{fp}\right|$

3.3 Measurement of the viewing angle

This subsection describes a method for measuring the viewing angle of the image. This method also assumes that a part of the ship's structure of the specified index exists in the image, as in subsection 3.2.

The positional relationship between the camera and the structure on the hull is measured. Fig.3 shows the example. The distances between the camera and both the ends P and Q of the structure on the hull are c and d, respectively, and e is the width of the structure. The apparent angle θ_{hr} of this structure is determined by formula (10).

$$\theta_{hr} = \arccos\left(\frac{-e^2 + c^2 + d^2}{2cd}\right) \ [\text{deg}] \tag{10}$$

Fig.4 is the image of the structure on the hull. In an ideal camera lens, the light angle ratio of the incidence and emergence is the same. Hence, the relationship between the apparent angle and the width of the structure in the image is proportional. When the width of the structure in the image (actual width is e) is x (pixels), the angle of bearings U per pixel element is described by formula (11).
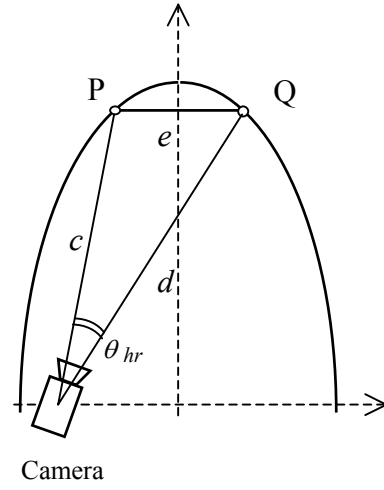

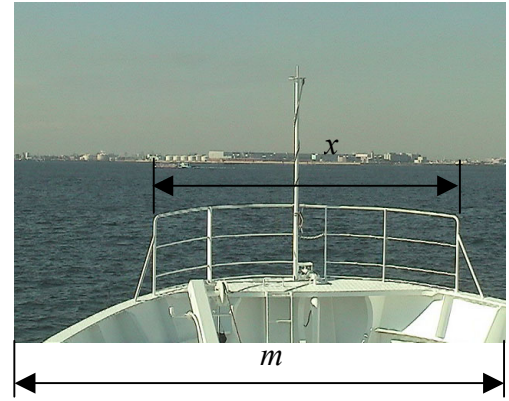Fig. 3   Arrangement of the camera and the structure on the hull.

Fig. 4   The image of the structure on the hull; x denotes the width of the structure and m, the width of this image.

$$U = \frac{\theta_{hr}}{x} \tag{11}$$

When the width of the image is m (pixels), the viewing angle V is given by formula (12). Since the size of the image used in this study is 640 × 480 (pixels), m would be 640 (pixels).

$$V = \theta_{hr}\left(\frac{m}{x}\right) \tag{12}$$

3.4 Measurement of the ship's bearings

This subsection describes a method for measuring the bearings of the ship extracted using the image processing technique described in Section 2. The distance between the X coordinate of the ship extracted from the image and the index of the hull (e.g., the flag pole) is defined as l (pixels). This relationship is shown in Fig.5.
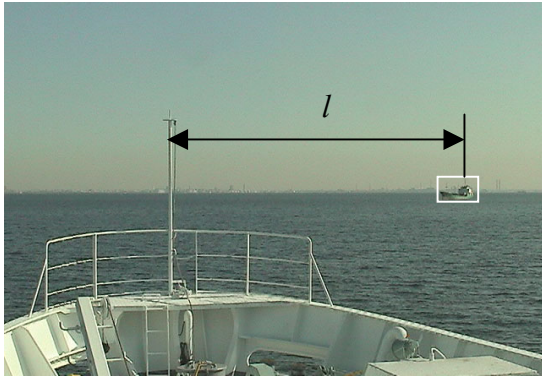
Fig. 5 Relationship between the index of the hull and the extracted ship; l denotes the distance between them.

Since the X coordinates of the index of the hull F_x have been obtained previously, if the X coordinates of the extracted ship S_x can be obtained, l can be expressed by formula (13).

$$l = |F_x - S_x| \qquad (13)$$

Based on the abovementioned results, the bearings of ship B can be calculated from formula (14).

$$B = B_{fp} + lU \qquad (14)$$

Formula (14) can be expanded to formula (15).

$$B = C_{gy} + 90 - \arccos\left(\frac{-a^2 + f^2 + b^2}{2fb}\right)$$
$$+ \arccos\left(\frac{-e^2 + c^2 + d^2}{2cd}\right)\frac{l}{x} \qquad (15)$$

Since variables a–f and x in formula (15) have already been measured, the bearings of the extracted ship B are calculated by feeding the experimental ship's course C_{gy} and the X coordinate of the ship S_x extracted from the image as inputs.

4. Experiment

The experimental method and summary are described below. Marine images were captured during a test cruise of the training ship Shioji Maru of Tokyo University of Marine Science and Technology.
Experiment Date: Nov. 29–Dec. 1, 2005
Experimental Sea Area: The offing of Urayasu of Tokyo Bay
Shooting Equipment: DCR-TRV70 (SONY)
Navigation Equipment: ECDIS JAN-901M (JRC)
Data Processors: ThinkPadT43 (IBM);
　　　　　　　　ApricotAL (MITSUBISHI)
Other measures materials:
　　　　Laser telemeter; DISTOmemo (Leica)
　　　　Capture board; GV-DVC3/CB (I/O DATA)
Experimental method:
1. Measure the relationship between the camera and forecastle using a laser distance meter.
2. Record the crossing of a ship ahead at sea using a video camera after visual and ECDIS confirmation.

3. Read out the gyrocompass course of the object ship, distance obtained by ECDIS, and other similar data so as to simultaneously record them into the video tape.
4. Measure the bearings of the object ship visually using a gyrocompass repeater and then record the measurement result using the video camera.

To prevent possible errors, the measured data are simultaneously recorded into the videotape in this experiment.

5. Results

5.1　Forecastle measurement

Fig.6 and Table 1 show the relative distance between the camera, index of the hull, and the structure of the ship and the measured data.
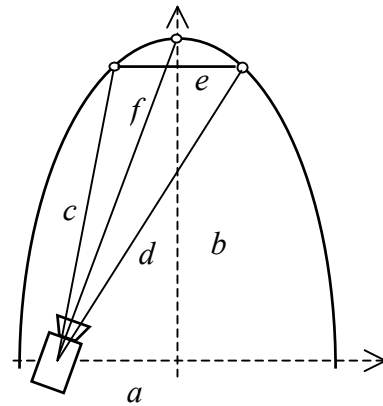

Fig. 6　Representative distance.

Table 1　Result of measuring each value

Symbol	Distance [m]
a	3.09
b	16.39
c	16.10
d	16.80
e	3.87
f	17.11

5.2　Comparison with visual observations

Six hours of video was recorded at sea during this experiment. From the recording, approximately two hours of video was relevant since it recorded ships within a distance of one mile.

A result of the comparison between the bearings of the extracted ship measured from the image and those obtained from visual observation is shown in Fig.7. The horizontal axis shows the differences between the measured data and the visual observation with a range of 0.5˚. The vertical axis denotes the number of incidents.

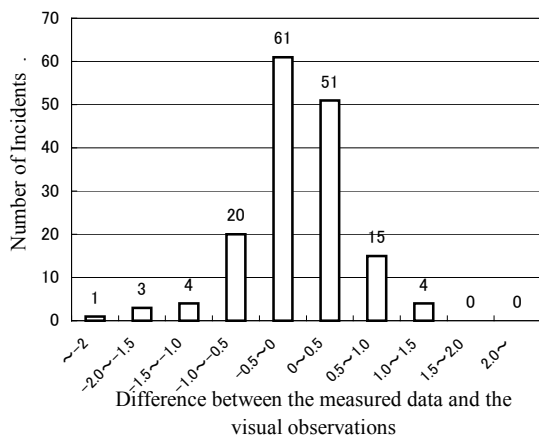Of the 159 incidents, more than 92% are within 1˚.

Fig. 7   Results of the comparison with the visual observations.

5.3   Superimposed compass scale

The compass scale was superimposed on the image, as shown in Figs.8 and 9. The date of recording, the experimental ship's course, and the bearings of the extracted ship are also described.

The compass scale was refreshed for each recording based on the bearings of the index of the hull and the viewing angle of the image.
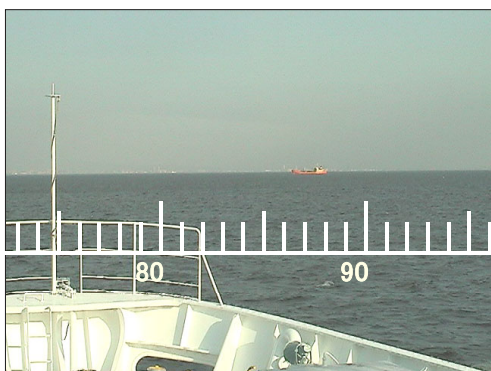

Fig. 8   Sample image with superimposed compass scale. Date: November 29, 2005; course of the experimental ship: 64.5˚; bearings of the detected ship: 87.9˚.
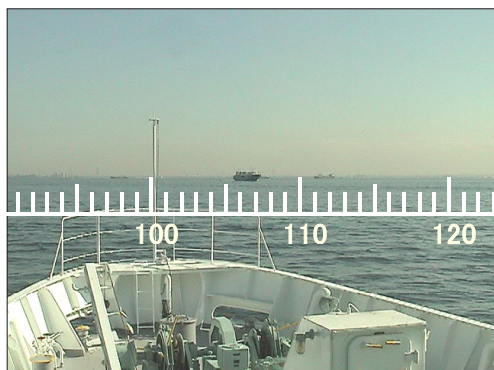

Fig. 9   Sample image with the superimposed compass scale. Date: November 20, 2005; course of the experimental ship: 90.0˚; bearings of the detected ship: 107.1˚.

6. Discussion

6.1   Processing time performance

According to the data processing capability of computer hardware used in this experiment, the region segmentation and match processing of a region required an average time of 1.0 s. Consequently, some processing of the entire image frame took several tens of seconds, and therefore, it is difficult to process it in real time by using the hardware resources actually used. The condition of the time performance required for the detection process is that a ship under detection processing in an image frame should not move beyond a range where the tracking process is valid, until detection processing is completed. In other words, the performance criterion is the condition whether tracking with a template can be performed on the image frame displayed after the completion time of detection processing, during which the template is extracted.

This condition depends considerably on the above described angle of view. If the images are wide-angled, the moving distance of a ship in an image is shorter than that in telephotographed images. Therefore, tracking is possible even when the detection process takes considerable amount of time. As mentioned above, from the viewpoint of the throughput of a computer, high-resolution, wide-range shooting are the ideal requirements.

This discussion leads to the following specific performance value required for implementation: the time required for the detection processing is approximately 5 s and that for the tracking process is approximately 0.5 s.

6.2   Data sharing

The objective of this study is to achieve the integration of the traditional navigation equipment (system) with an image processing system. If both the systems capture a ship in the same direction, it can be inferred that the ship is the same, and then the information can be shared between the systems.

Two cases are assumed under the condition that only one of the systems possesses the data. Each of these cases can be described as follows.

1.   Image processing system can detect the ship but the navigation equipment cannot.
     A small ship that is not equipped with an AIS and cannot be detected by radar is extracted from the image.
2.   Navigation equipment can detect the ship, but the image processing system cannot.
     Since the visibility or weather condition is bad, the image processing system cannot detect the ship.

Based on the results obtained, it can be inferred that the integration of the two systems can overcome the shortcomings of the individual systems.

Another possible case is that more than one set of data can be obtained from the navigation equipment because there exists another ship with the same bearings but located at a further distance. Since the lookout system commonly considers the nearest ship, if the data is limited to within several miles, data exchange duplication for long-distance ship can be prevented.

7. Conclusion

This paper proposes a method for the detection of moving ships using a "navigational image sequence", and a method for the measurement of the bearings of a ship from a camera's mounting position, the experimental ship's course, and the coordinates in the image. The experiment proved that by using the proposed method, the bearings of a ship can be obtained correctly. Furthermore, we generated a compass scale based on the bearings and the viewing angle, and demonstrated that it aids the lookout support system by superimposing the scale on the recorded video in real time.

In this experiment, the coordinates in the image were measured manually, but an automatic measurement was necessary to follow the camera's zoom or pan in real time. This issue will be studied in the future. As reported previously, a technique to achieve real time ship detection is under study.

We will examine the validity of this system integration by consolidating the specifications for information exchange with those for other navigation equipment.

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