Study on Estimating the Shape of a Ship by Integrating Radar Images

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ABSTRACT

The image of an object obtained by the radar is not corresponding to its true shape, because the image of an object observed by the radar is receiving an influence such as multiple-reflections and expanded in bearing because of the beam width of a radar. In addition, a radio wave does not hit the entire surface of an object. Therefore, the image of the front side of a ship facing a radar antenna corresponds to its true shape.
In this paper, a method to estimate a ship's shape by means of the integration of the front parts of images obtained from radars is proposed. In addition, a matter, which is observation error of each radar, in using multi-radars, and the process included in the proposed method for solving the matter, are described. As a result of the experiment, the accuracy of about 3 degrees in ship's heading and about 14 meters in length and about 9 meters in beam was obtained.

1. Introduction

The installation of AIS(Automatic Identification System) was started in July, 2002. And the dynamic data such as position, speed and course and the static data such as MMSI code, shape and destination are able to be obtained by AIS. However, the ships less than 300 tons engaging in an international voyage (less than 500 tons in case of a non-international voyage) are not necessary to be equipped with AIS. Furthermore, there are some ships not using AIS even if the installation is compulsory. Therefore a marine radar is still needed to get navigation information for navigator and observing marine traffic.
In such a background, some studies to estimate a ship's shape by the obtained radar image have been reported for observing marine traffic[(1),(2)]. But the image of an object obtained by the radar is not corresponding to its true shape [(3)], because the image of an object observed by the radar is expanded in bearing because of the beam width of a radar. In addition, a radio wave does not hit the entire surface of an object. Therefore, the image of the front side of a ship facing a radar antenna corresponds to its true shape. Especially in the case of observing an object which has a complex shape such as a ship, it is difficult to get an accurate shape from a radar image. In previous studies, the characteristic of such a radio wave was not considered in estimating a ship's shape from a radar image.
In this study, a method to estimate a ship's shape by means of the integration of the front parts of images obtained from radars is proposed in consideration of the above-mentioned problem. In addition, the estimation error occurs in integrating the images obtained multi-radars, because the images obtained from multi-radars can be affected by error of each radar. And the error is observation range error and bearing error in the radar. Therefore, the process for correcting the errors included in the proposed method is also described. And the accuracy of estimating a ship's shape by the proposed method is investigated by an experiment.

2. Method to integrate radar images

The concept of the proposed method is shown in Fig1. The method proposed in this study is a procedure to obtain the shape data by integrating the front part of the obtained images. Here, Fig.1 shows that the each front part of images obtained by Radar "A", Radar "B" and Radar "C" is integrated.

The configuration of the proposed method is shown in Fig.2. This system consists of a transmitter and a receiver. The transmitting and receiving mean not ones in radar, but ones in data transmission. In a transmitter, the obtained image and the radar's information, such as the position data, the measurement time and the beam width, are transmitted to a receiver. The each front part of the obtained images is integrated in the receiver.

Here, the images used for the integration are converted to position coordinates based on size per pixel of the radar screen. The integration and estimation are performed in the following procedures from (1) to (3).

(1) Processing the image expanding in cross-range direction is needed, because the image of an object observed by the radar is expanded in bearing because of the beam width of a radar.

(2) Correcting the affection by a difference of parameter and character of each radar is needed, because the integrated image can have errors by the difference in integrating images of multi-radars.
The errors are mentioned in 2-1, and the adjustment method is mentioned in Section 2-2.

(3) After the adjustment, the images obtained each radar are integrated. And the shape is estimated. Here, the shape consists of a ship's length, beam and direction in this study. The estimation method is mentioned in 2-3.

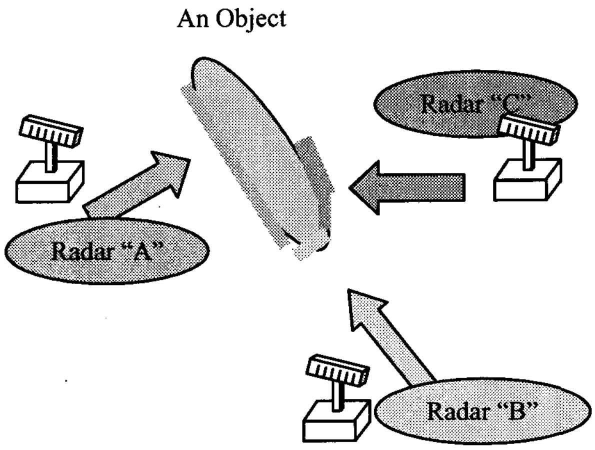


Fig. 1 The integration concept

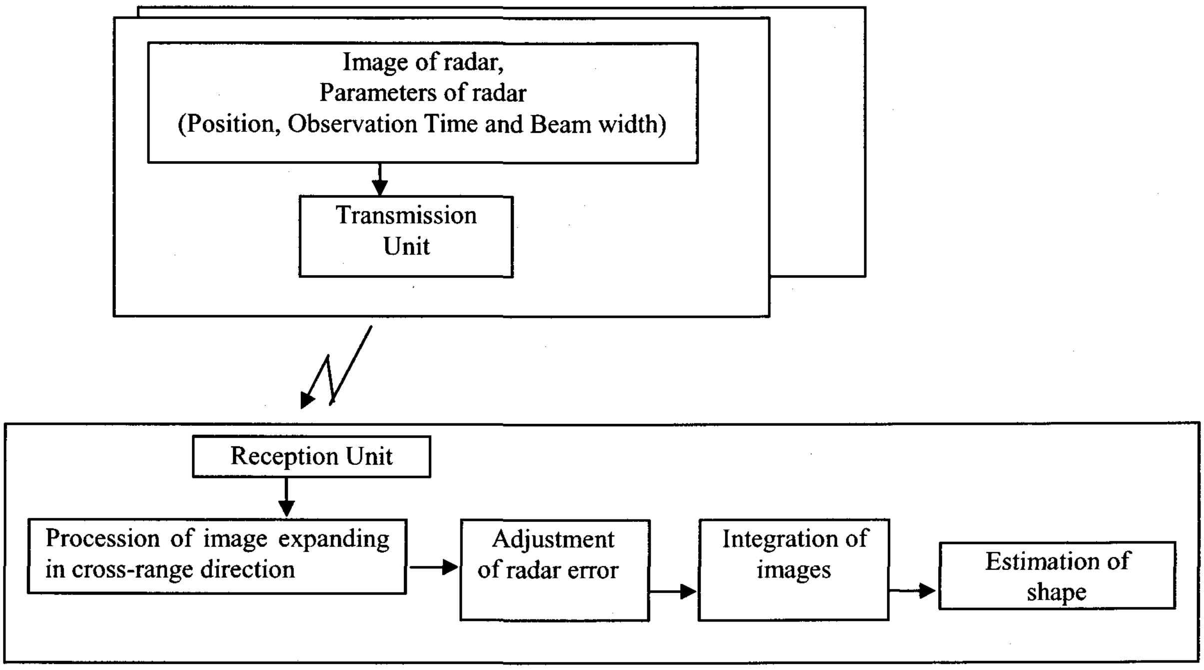


Fig. 2 The block diagram

2.1 Matter of integrating images obtained in multi-radars

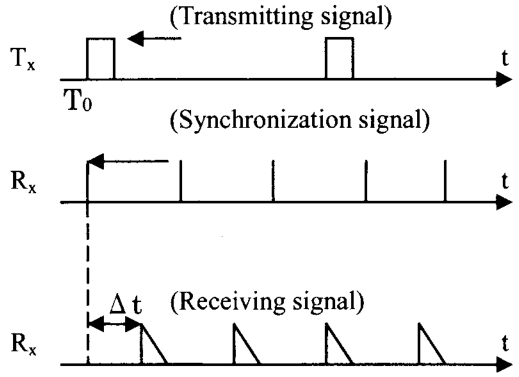
The position data used in the integration should be affected by errors of radar which consist of bearing error and distance error in the errors.
The former occurs by the disagreement between north direction of a radar antenna and true north direction and by expanding of image in bearing.
The latter occurs by an ambiguity by range resolution depending on pulse width, and by a difference of timing of synchronization signal and time of received signal as shown in Fig.3.

Here, radar images are converted to position coordinates by the radar position and the length of each pixel in the radar screen. Therefore, a position difference occurs by the resolution of the pixel. That is, the difference L is represented of length between the coordinate of an object (x_c, y_c) and the coordinate of the true position (x, y) of the object.

And when the segment L between these coordinates is projected to range direction and cross-range direction of radar, the each projected component affects both bearing error and distance error.
Therefore, there are three causes in bearing error ε_θ and ε_θ is obtained as below

$$\varepsilon_\theta = \varepsilon_{\theta n} + \varepsilon_{\theta b} + \varepsilon_{\theta px} \quad (1)$$

where $\varepsilon_{\theta n}$ is error by disagreement between north direction of a radar antenna and true north direction, $\varepsilon_{\theta b}$ is error by the expanding of image in bearing, and $\varepsilon_{\theta px}$ is error by the resolution of pixel of radar screen.



T_0: Reference time of a synchronization signal
Δt: A difference between each timing

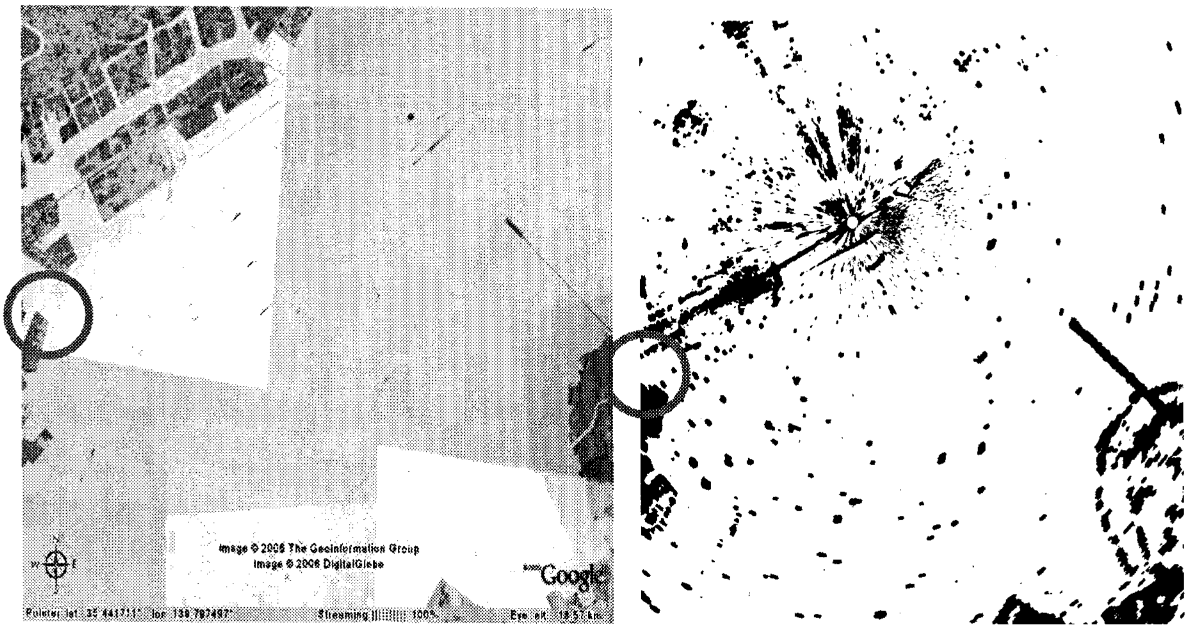
Fig.3 A difference of each timing

And distance error ε_R also includes three causes and is obtained as below.

$$\varepsilon_R = \varepsilon_{Rpw} + \varepsilon_{Rt} + \varepsilon_{Rpx} \quad (2)$$

where ε_{Rpw} is error by ambiguity by range resolution depending on pulse width, ε_{Rt} is error by a difference between timing of synchronization signal and time of received signal , and ε_{Rpx} is error by the resolution of pixel of radar screen.
Then, $\varepsilon_{\theta n}$, $\varepsilon_{\theta b}$ and ε_{Rt} are bias errors and $\varepsilon_{\theta px}$, ε_{Rpw} and ε_{Rpx} are random errors.

2.2 Adjustment method
In this section, a method to correct the bearing error and distance error mentioned in 2-1 is proposed. The method is a process to obtain the offset by comparing each land image of a radar and a map image. The offset is each value for correcting range error and bearing error. Each of the map images and the radar image used in this adjustment is shown in Fig.4(a) and Fig.4(b). The satellite image in GoogleEarth of Google Co.Ltd is used as the map image. Then the accuracy has been confirmed by checking it with chart and it is less than 10 meters.



(a) A map image (b) A radar image
Fig.4 The land images of a map and a radar

The land object surrounded by each circle in Fig.4(a), (b) is used in this explanation. Then the adjustment method is conducted in the procedure to (3) from (1). And the example of the process is shown in Fig.5.

(1) Images are extracted as the coast line, in both map image and radar image. They are surface images facing to the radar. Then, the error by expanding of the images in bearing images is corrected. And, the images are converted to coordinates that the origin is the position of the radar. Therefore, the one of bearing error is adjusted in this process.

(2) A regression line is drawn to the coast line as shown in Fig.5(c). Here, two by two regression line is drawn in a radar image and a map image. For this explanation, the lines are called Line(radar1), Line(radar2) in a radar image, and Line(map1), Line(map2) in a map image.

(3) The lines are integrated as shown in Fig.5(d). And each distance between the corresponding lines is compared. Then the offset of bearing and distance is found so that each distance between the lines becomes smallest.
Here, the distance between each line is shown as below.

$$d_1 = \frac{1}{N}\sum_{i=1}^{N}\left(x_n^{radar1} - x_n^{map1}\right)^2 + \left(y_n^{radar1} - y_n^{map1}\right)^2 \quad (3)$$

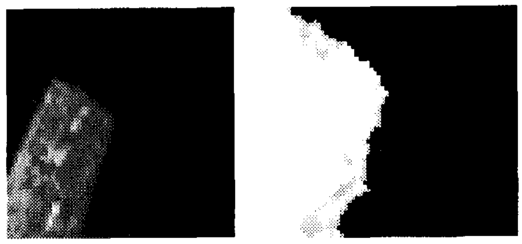
$$d_2 = \frac{1}{N}\sum_{i=1}^{N}\left(x_n^{radar2} - x_n^{map2}\right)^2 + \left(y_n^{radar2} - y_n^{map2}\right)^2 \quad (4)$$

$$d = \frac{1}{2}(d_1 + d_2) \quad (5)$$

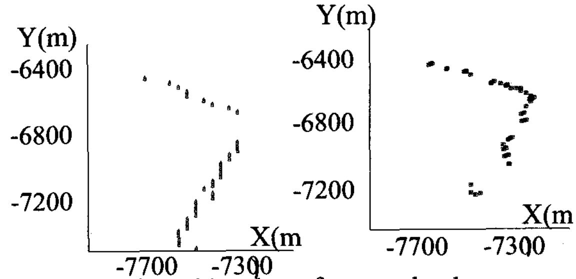
Where (x_n^{radar1}, y_n^{radar1}), (x_n^{radar2}, y_n^{radar2}), (x_n^{map1}, y_n^{map1}) and (x_n^{map2}, y_n^{map2}) are sequence of points composed of each line, and d_1 is the distance between Line(radar1) and Line(radar2), d_2 is Line(map1) and Line(map2).

Also, the sequences of points are composed at regular intervals of each line to the end in the map image from the point at the intersection with the Line(radar1) and Line(radar2) and Line(map1) and Line(map2).
And d_1 and d_2 are defined as the average of the distance of each corresponding point, as shown in equation (3) and (4). Then d is the average of d_1 and d_2.

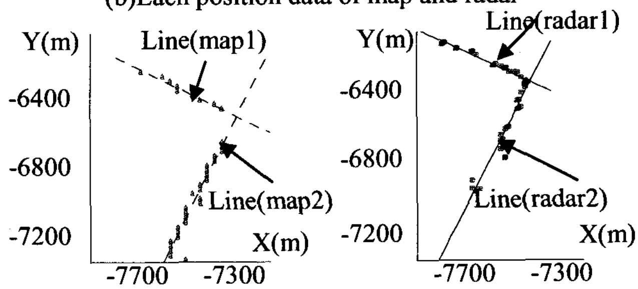
The each offset of direction and distance in this case shows 1.2degrees and 36meters. And the adjustment result by these values is shown in Fig.5(e).



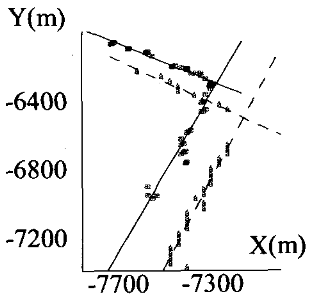
(a)Each land image from the (a) and (b) of Fig.4



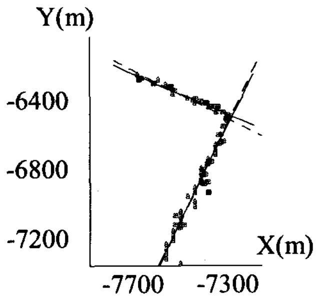
(b)Each position data of map and radar



(c) Each position data and regression line



(d)Integration of each regression line



(e)Adjustment Result

Fig.5 Process of the adjustment method
(Left images are "Map data" and Right images are "Radar data" in (a), (b) and (c))

In this case, the distance of this selected quay from the radar is 6.12NM and the direction is 225 degrees. And in the parameters of the radar, the pulse width is 0.4μsec, the beam width is 0.8 degrees and the size per pixel of the radar screen is 18 meters. The offset estimated from equation (1) and (2) except for bias error is that the bearing error is less than 0.0007 degree and that the distance error is less than 72 meters.
By comparing this offset and the offset obtained by this adjustment, it is cleared that affection of bias error in bearing error is big. And the reason why the random error is small is that a difference between size of pixel and an object in one of random error become small in proportion to the distance to the object from radar. Therefore, bias error in bearing error can be adjusted by this method.
And the random error is rejected by averaging offset obtained by selecting several lands or observing a land several times.

2.3 Method of estimating a ship's shape

In the estimation, the regression ellipse is drawn by the images obtained from each radar.
Then the major axis is regarded as a ship's length, and the minor axis is regarded as the width. There are three processing in this estimation method. The first is a process to reject the image affected by multiple-reflections. The second is a process to estimate a ship's shape by applying an ellipse regression to the integrated images. The third is a process to reject a widening part in the ellipse. These are mentioned in turn below.

The obtained image can be affected by multiple reflections. Therefore, rejecting the affected image by "cutline" is needed before estimating the shape [4]. The basic concept of cutline is shown in Fig.6.
Cutline is a line to tie the radar position and the blight point, of an object, which is closest to the radar position in the radar image. Also, cutline means an object does not exist between the radar and the line because it passes the closest blight point to the radar. .
So, the affected point obtained from other radar, existing between the radar and the cutline, is rejected by cutline as shown in Fig.6.

Then an ellipse regression is applied to the points processed by cutline, and a ship's shape is estimated. And, the major axis is regarded as a ship' length, and the minor axis is regarded as the beam.
Here, a regressed ellipse can be widened than the true shape. The widening ellipse affects the estimation of a shape. So, the widening part of the ellipse is rejected by Cutline. This is shown in Fig.7.

Therefore, the part surrounded between the ellipse and the cutline is the estimated shape. It is the part painted over with gray in Fig.7. And the major axis and minor axis of the ellipse except for the part processed by the cutline are length and beam. They are indicated by the arrowed lines in Fig.7. And direction is slope of the major axis.

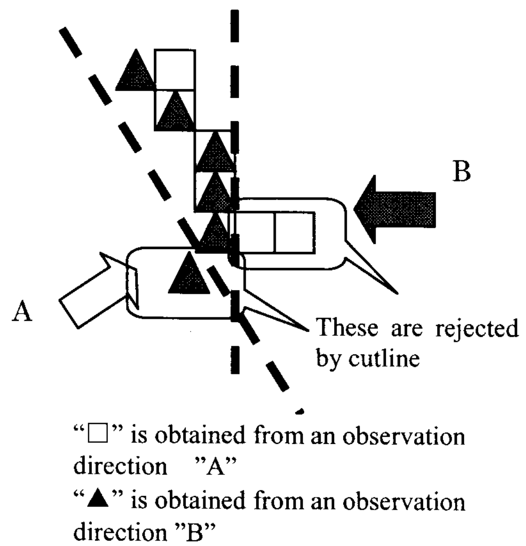


Fig.6 Process of the adjustment method

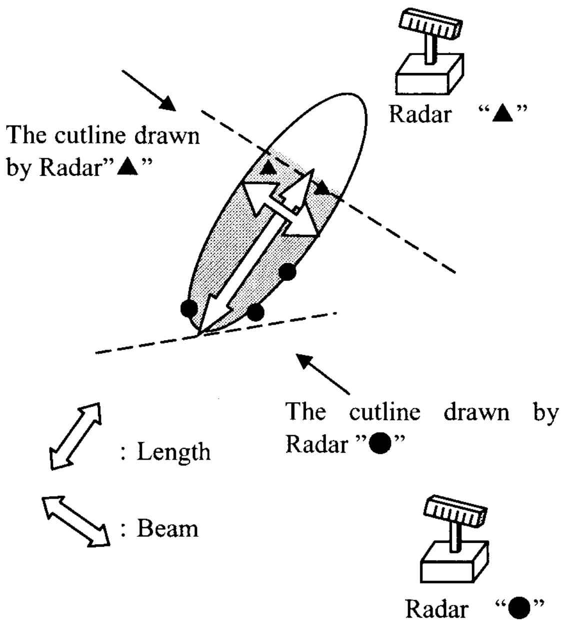


Fig.7 Process of the adjustment method

In observing an object from an oblique direction, the cutline drawn by this observation also is slanted to the

object. This line cannot reject a point affected by multiple reflections. This is shown in Fig.8. In this figure, the affected left mark cannot be rejected by the oblique cutline drawn by Radar "C". Moreover, the widening ellipse cannot be processed.
Therefore, an object should be observed from back and forth for getting the length, and observed from each side for getting the beam.

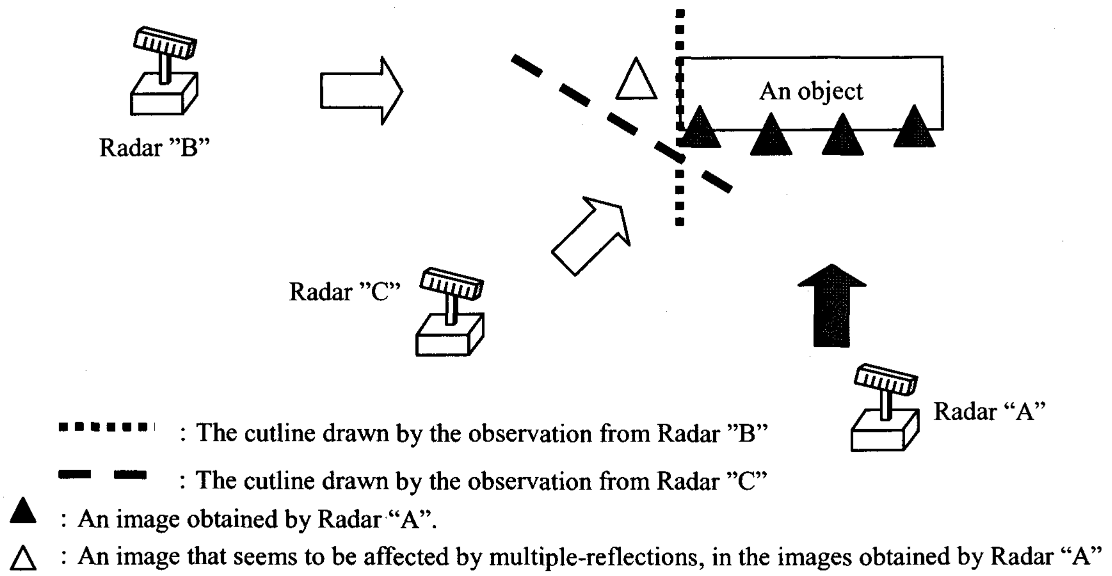


Fig.8 The observation direction to reject the image affected by multiple-reflections

3. Experiment and Results

An experiment is conducted for evaluating the proposed method in this study.
Two radars observe a ship at anchor in Kawasaki offing. Each of them is set in Higashi-Oghishima radar station and on a ship, Shioji-maru, for experiment.
And each image obtained by these radars is integrated and the shape of the ship at anchor is estimated. The name of the ship is "ANDESGUGHWAY", the length is 155 meters and the beam is 27 meters. And the object observed in this experiment is a ship installing AIS, because a comparison of a value obtained by this experiment and its true value is needed. But a ship's shape without AIS can be estimated in this proposed method, because a ship is observed by only radar.

3.1 The condition and the parameters

The each position of the observed ship and the radar is shown in Fig.9.
The number in Fig.9 indicates each position of radars. (1) is the radar in Higasi-Oghisima. (2) and (3) are each positions of Shioji-maru. That is, they are the positions of a ship observed by the radar of Shioji-maru. And the ellipse mark is a position of the observed ship. In addition, the directions and distances to each radar from the observed ship are shown in Fig.9.
Here, the observation time in (2) is different from (3), because the radar of (2) and (3) are the same radar. Therefore, the difference of the positions is revised by data of AIS. Also the directions of the observed ship in each observation are the same (they are 24 degree), so correcting them is not needed.
Parameters of radars are shown in Table1, and a picture of the observed ship is shown in Fig.10.

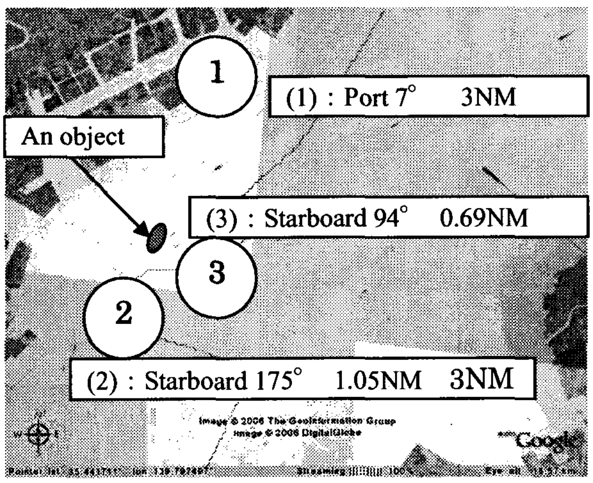


Fig.9 The positions of each radar and the object

Then, each point used for the adjustment in Highashi-Oghisima radar is a quay in Yokohama port (N35° 25′ 21″ , E139° 41′ 26″) and is radar beacon(N35° 24′ 53″ ,E139° 45′ 19″).
And each point used for the adjustment in the radar of Shioji-maru is quay in Daikoku Warf (N35° 27′ 18″ , E139° 42′ 08″) and in Oghisima Warf (N35° 27′ 51″ ,E139° 42′ 45″).
The point used for the adjustment is a place where there are not buildings around there. Moreover its point is using the edge because the extraction of the coastal line is easy.
And the offset is the average of the offsets in each radar, because the direction error and distance error have a random error.
These obtained offsets of the points selected in this experiment are following.

The each offset of direction and distance in the Higashi-Ogishima radar shows 1.2degrees and 36meters. And the each offset in the radar of Shioji-maru shows -0.85degrees and 33meters.

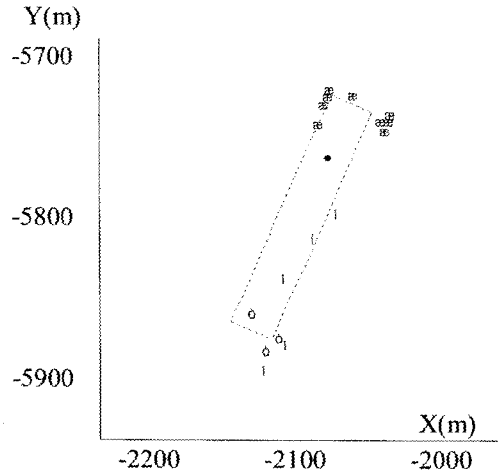
Table1 The parameters of radars used in this experiment

	Higashi Ogishima Radar	Shiojimaru Radar
Frequency	9410±30MHz	9410±30MHz
Pulse Width	0.4μsec	0.8μsec
Beam Width	0.8°	0.8°

Fig.10 The observed ship

3.2 Results and Discussions

The integration result is shown in Fig.11. The marks “●” in Fig.11 are data obtained by observing from the radar position “(1)” in Fig.9. ▲ are data obtained by observing from (2). ● are data obtained by observing from (3). Here, the adjustment method proposed in 2-2 has applied to the data. Here, the adjustment method proposed in 2-2 has been applied to the data.
And the rectangular in Fig.11 is the true shape obtained by AIS.



(The square in this figure is its true shape obtained by AIS)

● : The data observed from (1) in Fig.9
▲ : The data observed from (2) in Fig.9
◇ : The data observed from (3) in Fig.9

Fig.11 The result of the integration

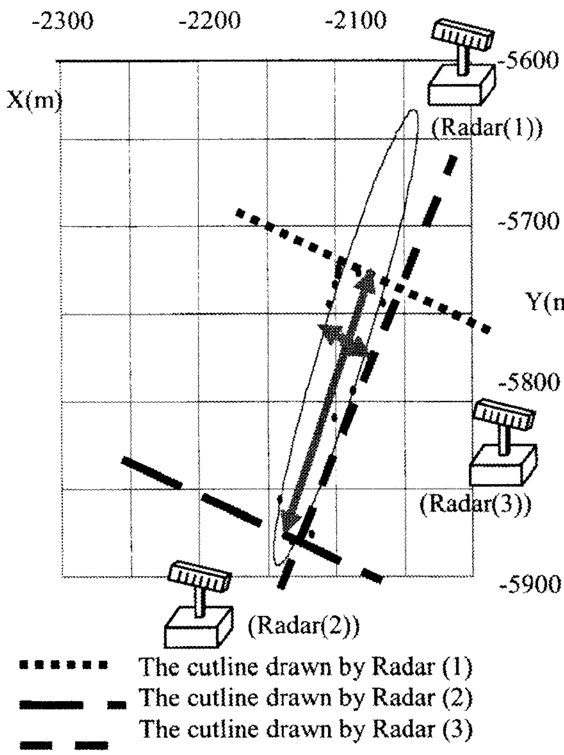


Fig.12 The ellipse that processed by the cutlines and the estimation of the length and Beam

Then, the shape is estimated by using the method proposed in 2-3. The ellipse and cutline obtained by the marks are shown in Fig.12. And the part surrounded by the ellipse and the cutlines is the estimated shape, the arrowed lines in this shape indicate the length and the beam. And the estimation result is shown in Table2. Fig.12 shows that the widening part of the estimated ellipse is rejected by the cutlines. Table2 shows a ship's shape is estimated with higher accuracy than previous studies [(1), (2)].
Moreover, as for the estimation result not using the cutline process for the expanding of a widening ellipse, the length is 279.7meters, the beam is 36.1meters and the direction is 21 degrees. Therefore, an effectiveness of the adjustment method is cleared by comparing it to the result of Table2.

Table2 The result of the estimation

	Direction (°)	Length (m)	Beam (m)
Estimated value	21.6	168.6	36.1
True value	24	155	27

4 Conclusions

A method to estimate a ship's shape by means of the integration of the front parts of images obtained from radars is proposed. Moreover, an adjustment method for correcting the error of each radar included in the proposed method is also proposed.
As a result of the experiment, the accuracy of about 3 degrees in ship's heading and about 14 meters in length and about 9 meters in beam were obtained. This shows that the accuracy obtained by this proposed method is higher than previous studies [(1), (2)].
Also, the shape of ship not installing AIS is able to be obtained, because a ship is observed only by radar in this method. And the images obtained by various marine radars can be used for the integration by adjusting errors of each radar. Therefore, this means that the case applying the estimation method increases.
In this experiment, a ship's shape at anchor is estimated. For the future study, estimating the shape of a navigation ship and communication system in this method will be investigated.

Acknowledgements

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Reference

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