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A Study for Technique of Detecting the Real-time Route Aberrance in the Passage Route Using Ship's Domain Theory

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Abstract : *This paper is to study a technique to detect the real-time route aberrance on the passage route using bumper area of the ship domain theory. In order to evaluate the risk of route aberrance, a quarter line was created between the center line and the outer line, and a passage route with the image line outside the outer line was designed. It calculated the real-time route aberrance with the vessel bumper area to measure the risk level on the passage route. The route aberrance using overlap bumper area was simulated through three kinds of scenario vessel at the designed passage route. In this paper, we proposed Ratio to Aberrance Risk as one of the evaluation parameter to detect the route aberrance risk at each sector in the passage route and to give the evaluation criteria of 5 levels for seafarer's navigation safety. The purpose of this work is to provide the information of the route aberrance to seafarer automatically, to make it possible to prevent the human errors of seafarer on the high risk aberrance route. As the real-time risk of route aberrance on the passage route is automatically evaluated, it was well thought that seafarer can have only a little workload in order to know the risk of route aberrance at early-time. Following the further development of this work, the techniques for detecting the real-time route aberrance will be able to use the unmanned vessel.*

Key Words : *Real-time route aberrance, Ship domain theory, Quarter line, Ratio to Aberrance Risk, The unmanned vessel*

1. Introduction

In general, seafarers of vessel try to keep near the center line in the passage route. However, the vessel may approach to go out of the outer line because of strong winds and swift sea currents.

In this case, seafarers want to know how much the vessel is aberrant from center line on the passage route to avoid the risk of the route aberrance.

If seafarers can check the extent of aberrance, they will take the action altering the course into the center line again to prevent the risk of the route aberrance.

The purpose of this study is to develop the technique which would be able to detect the risk of the route aberrance in the passage route in advance.

This study provides only a route aberrance at passage route. The key contents of ship's domain theory are to give enough safety boundary of a vessel. The bumper area of the vessels under ship's domain theory was used to identify a route aberrance (Fujii and Tanaka, 1971; Kunz, 1998).

Antecedent papers have two kind of conceptual bumper areas; the elliptical shape is considered in the original ship's domain theory by Fujii et al. (1984) and the square shape is a modified type to calculate bumper area in this work.

Although the elliptical shape gives more realistic form of a ship bumper area, it is more difficult to calculate overlapped bumper area than the square shape. So, this study used the square shape bumper (Gang et al., 2014).

In order to evaluate the risk of route aberrance, a quarter line was created between the center line and the outer line, and a passage route with the virtual line outside the outer line was designed.

The route aberrance was evaluated under the sum of sizes of vessel's bumper areas. The real-time route aberrance was calculated with the vessel bumper area to measure the risk level on the passage route.

The concepts for real time deviating of a bumper area from center line to outer line is introduced in this work to define the risk of route aberrance. The summing of bumper areas of a route aberrance on the passage route is used as one of the route aberrance risk parameter.

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The concept of the real-time route aberrance with bumper area calculation is verified through simulation tests with three traffic scenario bumpers in the designed passage route.

It was clearly known that the proposed technique of detecting the route aberrance can be used to prevent the risk of that in the passage route at early time.

The procedure of this study is shown below (Fig. 1).

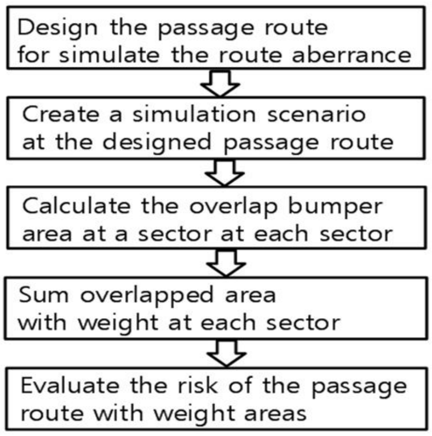

Fig. 1. The procedure of the study.

2. Designed passage route

2.1 Designed the passage route with 3 sectors

The master and a seafarer of a vessel try to keep themselves beside the center line to sail towards the port, but the vessel will drift outsides due to strong winds and sea currents in direction perpendicular to the straight route in bad weather conditions.

When the vessel is going to outside of the passage route, it is called the route aberrance. And they want to know in real time how much of the bumper area is deviated to outside.

So, the designed passage route is made of 3 sectors as shown on the Fig. 2 in order to simulate the route aberrance. Fig. 2 depicts a passage route with length of 10000 m and breadth of 900 m, the distance from the center line to the outer line is 900 m and each sector breadth is 450 m.

In addition, the image line was made off from the outer line at the distance of 450 m. The quarter line is on between the center line and the outer line.

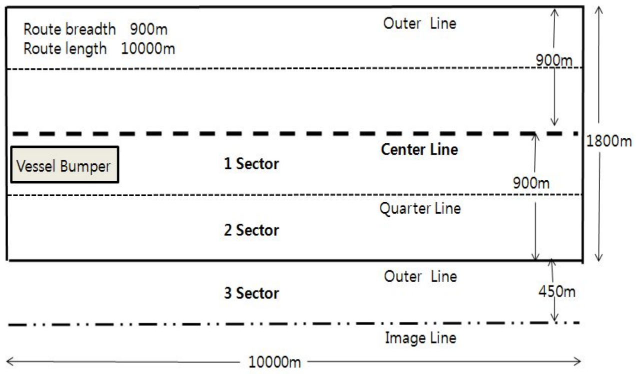

Fig. 2. Designed passage route with 3 sectors.

2.2 The shape of the route aberrance to deviate to starboard side

Fig. 3 shows the shape of the route aberrance which the vessel is going to move to starboard side direction from the center line to the image line in the designed passage route due to strong winds and sea currents. At the beginning, the start is beside the center line in the 1 sector. The scenario vessel is moving more and more to the 2 sector and next to the 3 sector due to the simulated bad weather conditions from port side direction.

The first step occurs in sector 1 between the center line and the quarter line. The second step is on the middle of quarter line. The third step occurs in sector 2 between the quarter line and the outer line. The fourth step is on the middle of outer line and the fifth step is on sector 3 between the outer line and the image line.

Moreover the fourth step can be thought as the risk of the route aberrance to evaluate any risk levels at given navigational situations.

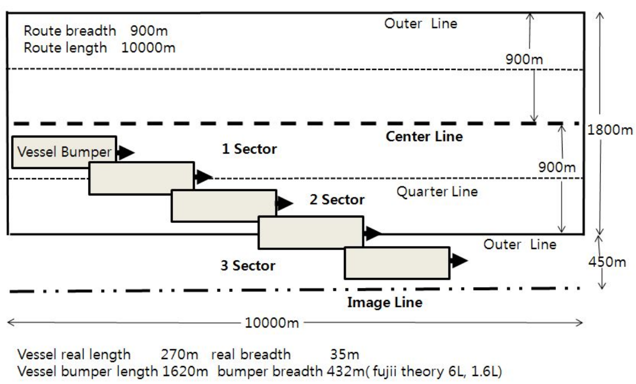

Fig. 3. The shape of the route aberrance to starboard side at real-time.

3. Application of the route aberrance calculation at real−time under ship's bumper area on the passage route

3.1 Simulation scenario

In this study, only vessel's LOA(Length over all) is need because of using Ship's Domain theory.

Table 1 shows the values of 3 scenarios in which A vessel has the length of 112 m and bumper area of 120,422 ㎡. B vessel has the length of 240 m and bumper area of 552,960 ㎡ and C vessel has the length of 369 m and bumper area of 1,307,146 ㎡. 3 scenario vessels are navigated with the same condition course of 225° and speed of 30 kts on the designed passage route.

Table 1. The values of vessel scenarios

Scenario Vessels	A	B	C
Passage routes	Width: 1800 m Length: 10000 m	Width: 1800 m Length: 10000 m	Width: 1800 m Length: 10000 m
Ship's technical data	Length: 112 m Breath: 18 m Course: 225° Speed: 30 kts	Length: 240 m Breath: 30 m Course: 225° Speed: 30 kts	Length: 369 m Breath: 51 m Course: 225° Speed: 30 kts

Fig. 4 shows that the width of each sector is 450 m and the length of passage route is 10000 m. The A vessel is moving from the start position which has the width of 1575 m and the length of 1111 m in the sector 1 to the destination position with the width of 600 m and the length of 8100 m with course of 225° and speed of 30 kts.

Scenario B vessel is seen on the simulation scene of the route aberrance on the Fig. 5 and the C vessel is depicted on the Fig. 6.

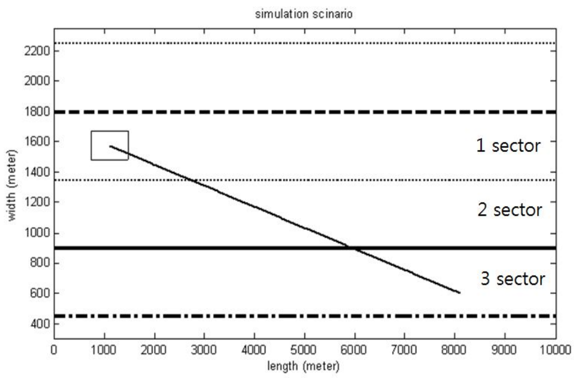

Fig. 4. Route aberrance simulation of scenario A vessel.

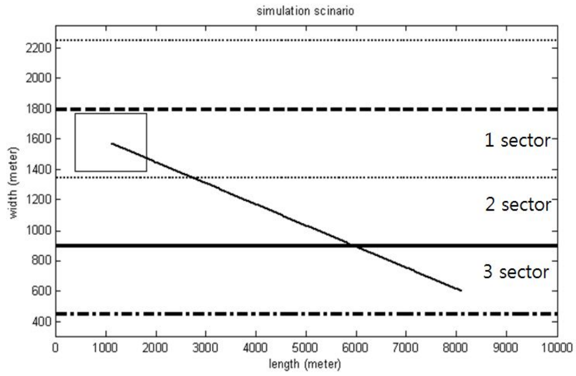

Fig. 5. Route aberrance simulation of scenario B vessel.

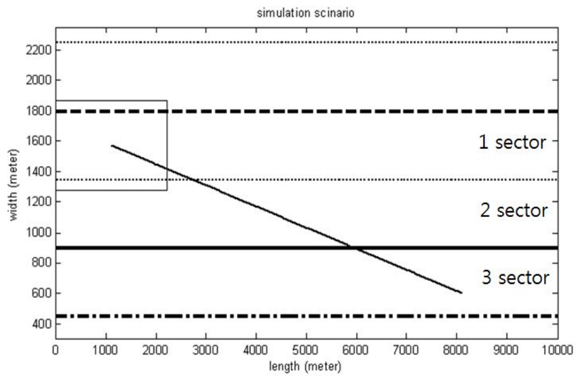

Fig. 6. Route aberrance simulation of scenario C vessel.

3.2 Calculation of overlapped bumper area at a sector

There is a bumper area calculated differently according to the ship's position that, the one is the bumper area equation (8.0 L × 3.2 L) in the open sea, the other is the bumper area equation (6.0 L × 1.6 L) in port by Ship's Domain theory (Fujii et al., 1984).

The bumper area equation of 6.0 and 1.6 means the weighting values to give the average size of bumper area defined in SD theory (Kunz, 1998). In this study, we used the bumper area equation (6.0 L × 1.6 L) in the designed passage route.

The bumper area of a scenario vessel as BA_i^t in Eq. (1), a sector area as S_j in Eq. (2) and Overlap bumper area (OBA) of a sector as $OA_{i,j}^t$ in Eq. (3) can be calculated as follows.

$$BA_i^t = (6.0\,L) \times (1.6\,L) \tag{1}$$

$$S_j = width(450m) \times length(10000m) \tag{2}$$

$$OA_{i,j}^t = (BA_i^t \cap S_j) \tag{3}$$

where:
i is the scenario vessel index.
i = 1, 2, 3, ⋯, I
j is the sector index
j = 1, 2, 3, ⋯, J exist only 3.
t ie the time.
t = 0, 1, 2, ⋯, T is discrete variable.
BA_i^t is the bumper area of scenario vessel.
S_j is the sector area which each is the same.
L is the length of scenario vessel in designed passage route.
$OA_{i,j}^t$ is OBA in each sector at time t.

Fig. 7 presents the results of overlap A vessel's bumper area in each sector. The axis of X presents an overlap area and the axis of Y is a distance of the designed passage route.

When the A vessel's bumper area is in sector 1, it makes the overlap area itself. while moving to sector 2, the bumper area is decreasing in sector 1 and increasing in sector 2 at the same time. while in sector 2, the A vessel's bumper area becomes itself again.

The results shows that the A vessel's bumper area appears three times in each sector. On the other side, when the A vessel's bumper area exists between each sector, it shall be denoted simultaneously as decreasing at prior sector and increasing at next sector.

The overlap bumper area of B vessel's simulation results is depicted in Fig. 8 and Fig. 9 shows the C vessel's result.

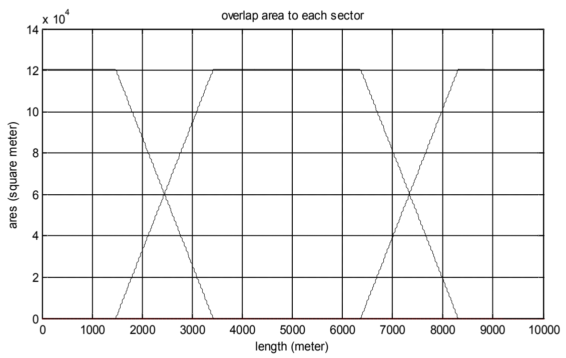

Fig. 7. OBA of scenario A vessel in each sectors.

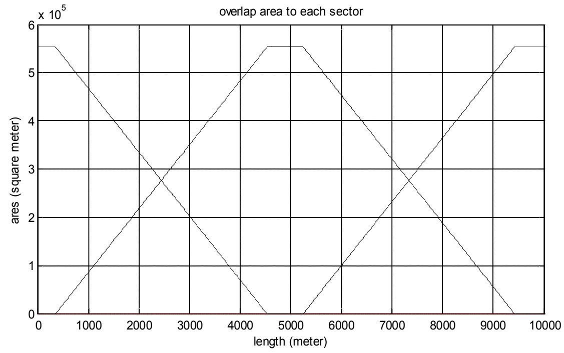

Fig. 8. OBA of scenario B vessel in each sector.

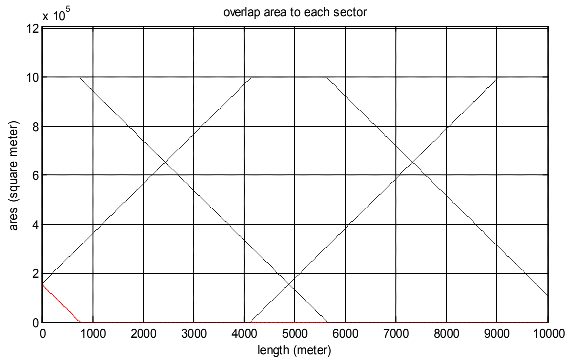

Fig. 9. OBA of scenario C vessel in each sector.

3.3 The summing of the overlap bumper areas(OBA) with weight in each sector

Fig. 10, presents the summing of the OBA with weight in each sector. When the OBA is in sector 1, the summing of OBA ($OA_{i,j}^t$) is itself. While moving between the sector 1 and the sector 2, the summing of OBA is increasing up to 2 times of OBA ($OA_{i,j}^t$).

The summing of OBA becomes 2 times of OBA ($OA_{i,j}^t$) in the sector 2. It is shown that the OBA is summing from 2 times to 3 times during the moving between the sector 2 and the sector 3.

This technique of the summing of Vessel bumper area with weight in each sector at real-time is used in order to detect the risk level of route aberrance.

The term SA_i^t is the summing of OBA with weight in each sector. SA_i^t denoting as in discrete Eq. (4) and consecutive Eq. (5) can be calculated as follows.

$$SA_i^t = \sum_{t=1}^{T} \sum_{j=1}^{J} OA_{i,j}^t \text{ (Discrete equation)} \quad (4)$$

$$SA_i^t = \int_{t=0}^{T} \int_{j=1}^{J} OA_{i,j}^t \text{ (Consecutive equation)} \quad (5)$$

Fig. 11 shows the summing results of scenario B vessel's OBA with weight in each sector (SA_i^t) at real-time.

The A Vessel and the B vessel's bumper sizes are different. Thus the B vessel's SA_i^t presents the different result from the A vessel in Fig. 11.

According to this study, if vessel bumper area's width applied by Ship's domain Theory is bigger than each sector's width the summing area of the scenario vessel with weight is not calculated well cumulatively as shown in Fig. 12.

The reason is that the bumper area width of the scenario C vessel's is bigger than the 1 sector's width.

By the results of the simulation, it becomes known that the variable bumper area in that case is needed, and the variable bumper width should be smaller than the width of a sector.

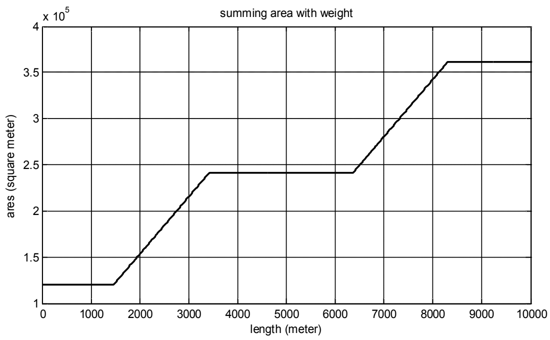

Fig. 10. The summing of the A vessel bumper area with weight in every sectors.

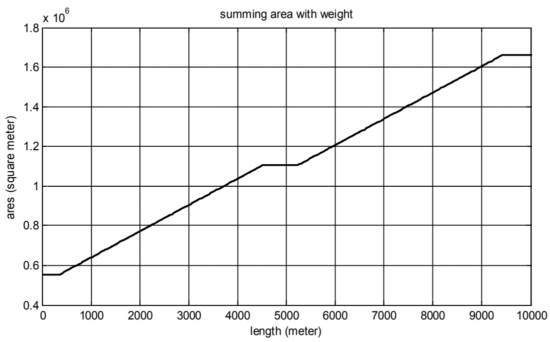

Fig. 11. The summing of the B vessel bumper area with weight in every sectors.

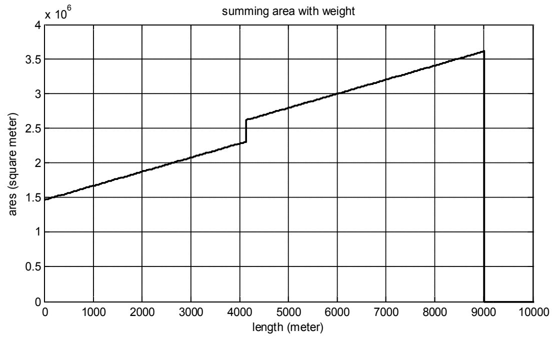

Fig. 12. The summing of the C vessel bumper area with weight in every sectors.

4. Techniques of detecting the real-time route aberrance at each sector

The ratio between the summing of OBA with weight in each sectors ($SA_{i,j}^t$) and the vessel bumper area (BA_i^t) is used as one of evaluation parameter to detect the risk of route aberrance at each sector at the passage route. Ratio to Aberrance Risk (RAR)Γ_i^t can be calculated as follows.

$$\Gamma_i^t = \frac{SA_i^t}{BA_i} \quad (6)$$

Γ_i^t means the Ratio to Aberrance Risk (RAR), which is the ratio between the summing of overlap bumper area in each sector ($SA_{i,j}^t$) and the vessel bumper area (BA_i^t).

This RAR denotes integer index as from 1 to 3.

In Fig. 13, the axis of X in the graph of RAR represents the value of the ratio from 1 to 3.

Fig. 13 shows the simulation scenario A vessel. Fig. 14 is the simulation scenario B vessel. However, the scenario C vessel could not be evaluated properly because its bumper width is bigger than the width of sector 1. The RAR is divided into 5 steps to evaluate the risk level of route aberrance.

First level of the value of the ratio 1 is safety. When the value of ratio increase from 1 to 2, it means the beginning of route aberrance and should inform the caution of the risk level 2.

When the value of ratio is evaluated exactly 2, it means the warning of risk level 3 going to route aberrance out of the sector 1. When from 2 to 3, it means almost occurrence of aberrance with the danger of risk level 4. If the value of the ratio is more than 3, it means a full aberrance.

Table 2 shows that the risk level of route aberrance is divided into 5 evaluation steps.

Table 2. Aberrance risk level in 5 steps of the ratio (RAR)

ratio	risk level	meaning	remarks
1	1	good	safety
1~2	2	caution	beginning aberrance
2	3	warning	going aberrance
2~3	4	danger	almost aberrance
<3	5	very danger	full aberrance

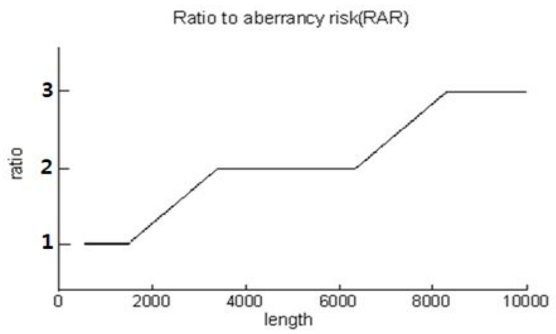

Fig. 13. Ratio to aberrance risk (RAR) in A vessel.

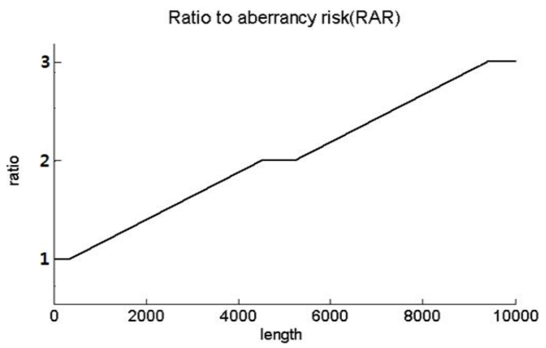

Fig. 14. Ratio to aberrance risk (RAR) in B vessel.

5. conclusion

The techniques of detecting the real-time route aberrance by using vessel bumper area under the ship domain theory were applied to obtain the route aberrance risk in the passage route.

The route aberrance using overlap bumper area was simulated through three kinds of scenario vessel at the designed passage route.

In this paper, we proposed Ratio to Aberrance Risk(RAR) Γ_i^t as one of the evaluation parameter to detect the route aberrance risk at each sector in the passage route and to give the evaluation criteria of 5 levels for seafarer's navigation safety.

Through the analysis of simulated vessel tracks in the designed passage route, it became known that the simulation results from 5 risk evaluation steps of route aberrance were processed well. However, in the scenario vessel which had bigger bumper area's width than a sector's width, the risk of route aberrance could not be evaluated.

It was clearly known that a vessel with bigger bumper area than each sector's width needed the reduced bumper area.

Moreover, following the further development of this work, the techniques for detecting the real-time route aberrance will be able to use the unmanned vessel.

These proposed techniques can provide us with the information on route aberrance at each sector in the passage route.

When they sail on the passage route in harbour, we are going to develop the early warning system for seafarers to be able to recognize the risk of route aberrance in advance.

Acknowledgement

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