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A Study of a Collision Avoidance Support System

Jun Kayano
Department of Maritime Systems Engineering. Tokyo University of Maritime Science and Technology
Tokyo, Japan

Hayama Imazu
Department of Maritime Systems Engineering. Tokyo University of Maritime Science and Technology
Tokyo, Japan

Abstract— Recently, shipping industries has become required safety ship operation with fewer crews. On the other hand, recent progress of information and telecommunication technologies is remarkable. The industries would also like to employ these technologies to make the ship operation safer and more efficient. In this study, we propose and discuss collision avoidance support system. The support system proposed in this paper warns the watch officer of the danger and starts planning collision evasion route with the collision avoidance algorithm when the ship faces the risk of collision. Then it shows the most feasible evasion route on main console. For searching the optimal route under collision avoidance support system, this study considers two methods. To evaluate the effectiveness of the methods, some simulations are carried out. In this paper, the details of each method and the simulations that is carried out to evaluate their effectiveness are described.

***Keywords*—Ship, Navigation, Collision Avoidance support system, OZT.**

I. Introduction

Recently, shipping industries has become required safety ship operation with fewer crews because experienced seafarers has diminished by their aging, while demands for the modal-shift from land transportation to sea has increased and commercial competition of shipping business has been strengthened. On the other hand, recent progress of information and telecommunication technologies is remarkable. The industries would also like to employ these technologies to make the ship operation safer and more efficient. Applying these technologies to marine transportation systems contributes to develop collision avoidance support for ships' bridge operation.

In this study, we propose and discuss collision avoidance support system. The navigation support system proposed in this paper warns the watch officer of the danger and starts planning collision evasion route with the collision avoidance algorithm when the ship faces the risk of collision. Then it shows the most feasible evasion route on main console to confirm. After confirmation of that route the ship is automatically controlled to follow the evasion route, until the danger passed. For searching the optimal route under collision avoidance support system, this study considers two methods, that is, the method of using lattice-like reference points and the method by using OZT. To evaluate the effectiveness of the methods, two kinds of simulation of two ships' encounter and the simulation of three ships' encounter are carried out. In this paper, the details of each method and the simulations that is carried out to evaluate their effectiveness are described.

II. COLLISION AVOIDANCE ALGORITHM

Watch officers engage in collision avoidance operation repeatedly. Especially in congest sea area, such operation occupies majority of their works. To avoid collision, they have to get information for assessing risk of collision, to plan evasion route the ship can adopt, and to decide which route is secure. In congested sea area, sometimes they devote their attention to such operation.

To reduce the workload, we propose a collision avoidance algorithm to make an optimal plan for evasion action. The optimal plan should be safe, efficient and understandable for watch officer. Therefore, it needs to consider the risk of collision, deviation from planned route and emotional toll in watch officers, legality and practicality.

In this section, we describe how to make an evasion route. The procedure for searching optimal route is following.

1) Placing reference points

To search the long-term and complicated route, the reference points are considered and then, the optimal route is calculated.

To decide the reference points, it needs to consider the forecast period and time interval. The forecast period is decided by considering projected performance, accountability and change of situation. Accountability means accuracy of position forecast and is dependent to information error of targets and to forecast error of disturbance. Obviously, we would like to take the route which forecasts as far as possible and is well planned. However, it will have been wasted by changes of accountability and situation. Time interval means how many stages the forecast period is divided into for calculation. It is decided by considering number and complication of calculation. If this value is set short, the number of the routes which should be evaluated become more and it will take time to calculate, while the elaborate and complicated route come to be possible.

In this study, the temporal prospect is set 30 minutes and the time interval is set 4 stages (6 minutes/ 6 minutes/ 6 minutes/ 12 minutes) based on the value suggested by Imazu.

2) Making possible routes

Among lines connected each reference point s, feasible routes are calculated with consideration of possible ship speed and capability of course change.

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3) Selection of the most efficient route for evasion

The efficient route is selected based on following criteria.

- Danger of collision: Degree of danger based on Distance Closest Point of Approach（DCPA）.
- Deviation from planned route: Geographical safety and efficiency
- Emotional toll on sailors: Avoid frequent course change.
- Legality / Practicality

In the selection, each value is summed up with weighted as the total evaluation value for selection.

Recalculation is occurred, when the ship passes the reference point, 6 minutes has been passed from last calculation, or dangerous situation occurs on the calculated route because of changes of target's behavior. For setting the reference point, this study considers the method of using lattice-like reference points and the method by using OZT. From next section, the details of each method are described.

A. The method of using lattice-like reference points

On the 1st stage, this method sets the reference points to where the ship can move in setting speed by each 15 degree in the range of 45 degree of each side. It also sets them to where it can move in its 70 % of setting speed by each 15 degree in the range of 45 degree of each side. After 2nd stage, it sets them to the square lattice 25 % of setting speed on a side as shown in Figure 1.

Also, as restriction in searching the optimal route (restriction on moving between reference points), the points with alternating course over 45 degrees and the points the ship cannot reach in from its 70 % to 100 % of setting speed are excepted from calculation.

B. Method for planning evasion route using OZT

The difference from the method of using lattice-like reference points is a selection method of reference points to make candidates of the route. ... by Target (OZT)[1] is used to sele... ng route.

Figure 2 is a conceptual image of OZT. The ship shape placed in center is own ship and target ship comes closer from right side of own ship. The arrow-headed thick line from the own ship is estimated future trajectory of the own ship and dotted arrow-headed lines are possible direction of own ship course. The arrow-headed line from the target is estimated future trajectory of the ship and circles on the line is Obstacle Zone by Target. The existence of the OZT is calculated from present position to a certain time (in this case 30 minutes) in every periodic time interval (in this case 15 seconds). The existence of OZT or not is calculated based on the time to reach the target ship to a calculation point and the probability that the own ship changed its course to the point and the ship reaches to the point at the time.

The probability is calculated with consideration of sensor errors. When the probability is exceeded a threshold, the point is marked as the OZT. As the OZT is a possible point of collision, we place the reference points in four corners around the zones with suitable margins. The most important merit to use OZT is it can make clear the target ship of selected route. By placing the reference point at a certain ship, the obtained route is directed to the related point of the ship, such as just the stern of the ship. Therefore, it is easy to recognize avoiding ship and type of action type of evasion with the proposed route. This method placing reference point based on the OZT.

The reference points for passing point are placed the four corner points of the OZT to keep out from collision danger area. In addition to the reference point of OZT, some reference points to related planed route and calculation stages are placed as shown in Figure3.

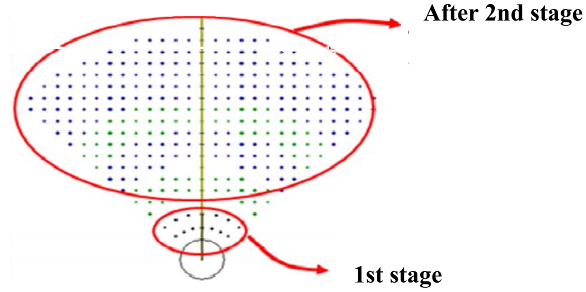

Figure 1 The method of using lattice-like reference points

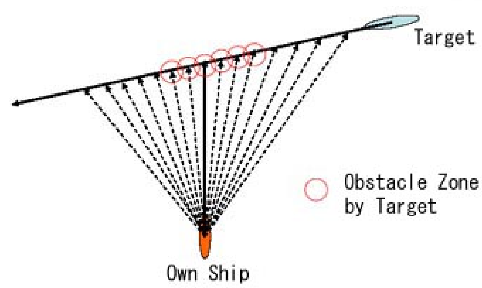

Figure 2 Image of OZT

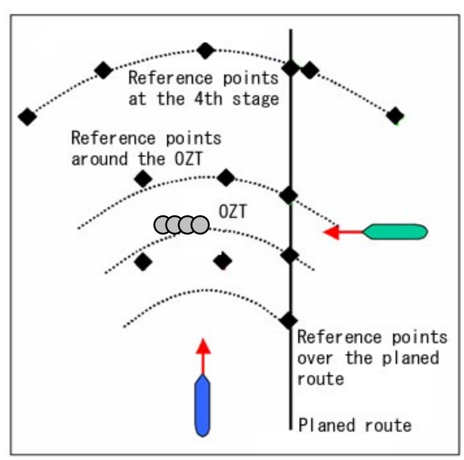

Figure 3 Arrangement of Reference points

III. Evaluation of the Collision Avoidance Algorithm

To evaluate the effectiveness of the algorithm, two kinds of simulation of two ships' encounter and the simulation of three ships' encounter are carried out. The results are shown as follows. In these experiments, each ship is operated based on the same algorithms. The following conditions are set because it is convenient for analyzing the results.

(Conditions of ships)

- Each ship has same system and the safety distance is set 0.5 miles.
- Each ship avoids collision independently and does not exchange information.
- As the model of ships, the same first order model[2] is used.

(Conditions of environment)

- The sea area is set wide.
- The influence of disturbance is not made account.

A. Head on situation

This simulation sets the time until the own ship (000deg, 12 knot) reached the target (180deg, 12 knot) most closely to 30 minutes and the distance when the own ship reached the target most closely to 0 mile. The results by applying the method of using lattice-like reference points are shown in Figure 4. Figure 4 (a) shows the true plot, Figure 4 (b) shows the relative plot with a central focus on the own ship and Figure 4 (c) shows the time series of every ship's course change. The result by applying the method for planning evasion route using OZT is shown in Figure 5. Figure (a) shows the true plot, Figure 5 (b) shows the relative plot with a central focus on the own ship and Figure (c) shows the time series of ship's course change. As a result,

- Passing distance by applying the method of using lattice-like reference points is 1.00 mile and that by applying the method for planning evasion route using OZT is 0.97 mile. Both methods ensure the safety margin for evasion action adequately.
- Maximum deviations from the route of the method of using lattice-like reference points is 0.56 mile and that by applying the method for planning evasion route using OZT is 0.48 mile. The lost of advance by applying the method of using lattice-like reference points is 0.23 mile and that by applying the method for planning evasion route using OZT is 0.02 mile. They are little.

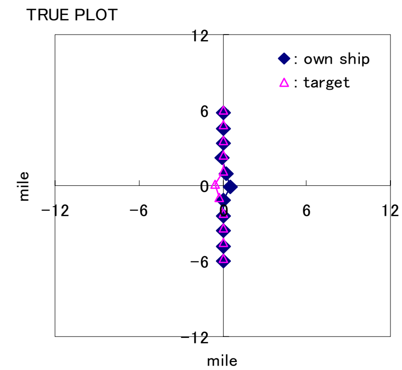

Figure 4 (a) True plot of simulation result by applying the method of using lattice-like reference points

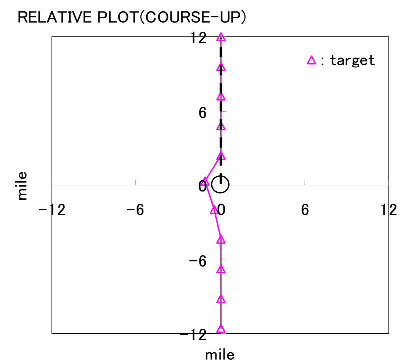

Figure 4 (b) Relative plot of simulation result by applying the method of using lattice-like reference points

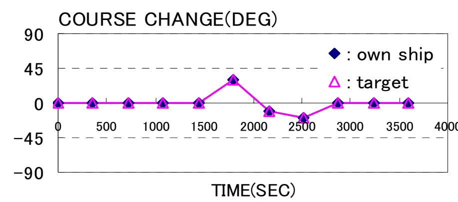

Figure 4 (c) Time series of ship's course change of simulation result by applying the method of using lattice-like reference points

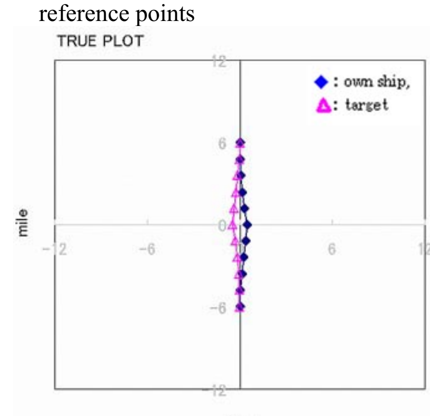

Figure 5 (a) True plot of simulation result by applying the method for planning evasion route using OZT

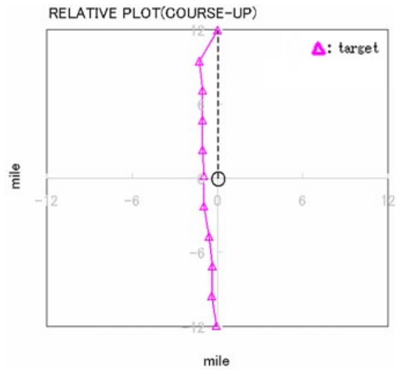

Figure 5 (b) Relative plot of simulation result by applying the method for planning evasion route using OZT

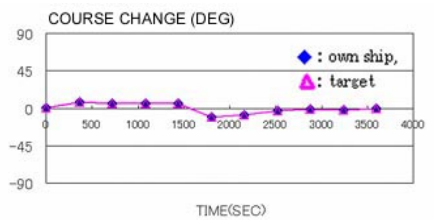

Figure 5 (c) Time series of ship's course change of simulation result by applying the method for planning evasion route using OZT

B. *Crossing situation*

This simulation sets the time until the own ship (000deg, 12 knot) reached the target (270deg, 12 knot) most closely to 30 minutes and the distance when the own ship reached the target most closely to 0 mile.

The results by applying the method of using lattice-like reference points are shown in Figure 6. Figure 6 (a) shows the true plot, Figure 6 (b) shows the relative plot with a central focus on the own ship, Figure 6 (c) shows the time series of every ship's course change. The results by applying the method for planning evasion route using OZT are shown in Figure 7. Figure 7 (a) shows the true plot, Figure 7 (b) shows the relative plot with a central focus on the own ship, Figure 7 (c) shows the time series of ship's course change.

As a result,

- Passing distance by applying the method of using lattice-like reference points is 0.50 mile and that by applying the method for planning evasion route using OZT is 0.60 mile. Both methods ensure the safety margin for evasion action adequately.
- Maximum deviations from the route of the method of using lattice-like reference points is 0.30 mile and that by applying the method for planning evasion route using OZT is 0.68 mile. The lost of advance by applying the method of using lattice-like reference points is 0.44 mile and that by applying the method for planning evasion route using OZT is 0.16mile.

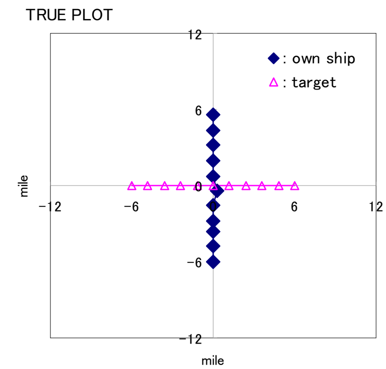

Figure 6 (a) True plot of Simulation result by applying the method of using lattice-like reference points

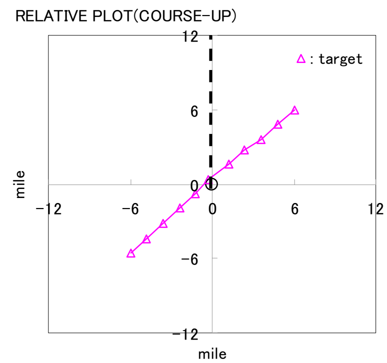

Figure 6 (b) Relative plot of Simulation result by applying the method of using lattice-like reference points

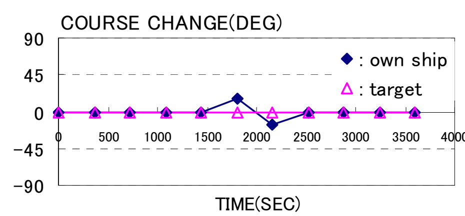

Figure 6 (c) Time series of ship's course change of Simulation result by applying the method of using lattice-like reference points

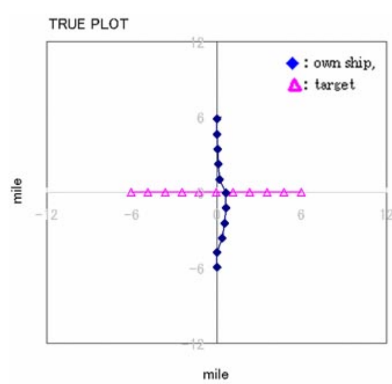

Figure 7 (a) True plot of Simulation result by applying the method for planning evasion route using OZT

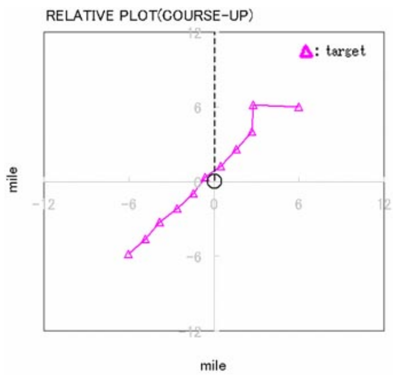

Figure 7 (b) Relative plot of Simulation result by applying the method for planning evasion route using OZT

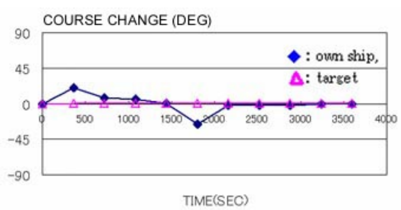

Figure 7 (c) Time series of ship's course change of simulation result by applying the method for planning evasion route using OZT

C. The situation of avoiding three ships' collision

This simulation sets the time until the own ship (000deg, 12 knot) reached the target I (120deg, 12 knot) and the target II (240deg, 12 knot) most closely to 30 minutes and the distance when the own ship reached the targets most closely to 0 mile.

The results by applying the method of using lattice-like reference points are shown in Figure 8. Figure 8 (a) shows the true plot, Figure 8 (b) shows the relative plot with a central focus on the own ship, Figure 8 (c) shows the time series of every ship's course change. The results by applying the method for planning evasion route using OZT are shown in Figure 9. Figure 9 (a) shows the true plot, Figure 9 (b) shows the relative plot with a central focus on the own ship, Figure 9 (c) shows the time series of ship's course change. As a result,

- Passing distance by applying the method of using lattice-like reference points is 0.86 mile and that by applying the method for planning evasion route using OZT is 2.61 mile. Both methods ensure the safety margin for evasion action adequately.
- Maximum deviations from the route of the method of using lattice-like reference points is 0.30 mile and that by applying the method for planning evasion route using OZT is 1.85 mile. The lost of advance by applying the method of using lattice-like reference points is 0.44 mile and that by applying the method for planning evasion route using OZT is 0.73 mile.

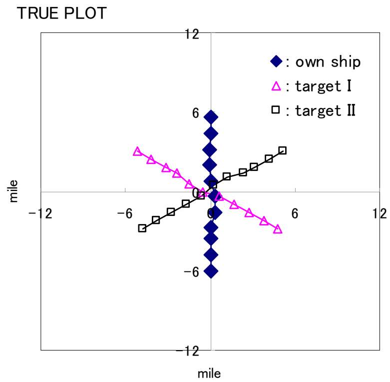

Figure 8 (a) True plot of Simulation result by applying the method of using lattice-like reference points

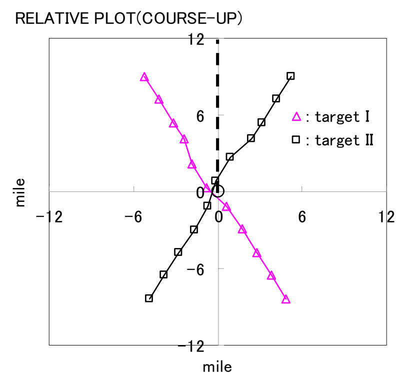

Figure 8 (b) Relative plot of Simulation result by applying the method of using lattice-like reference points

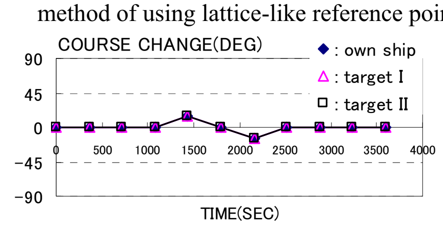

Figure 8 (c) Time series of ship's course change by applying simulation result of the method of using lattice-like reference points

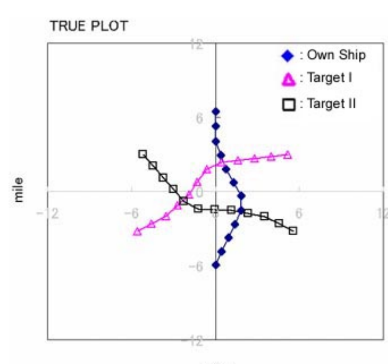

Figure 9 (a) True plot of Simulation result by applying the method for planning evasion route using OZT

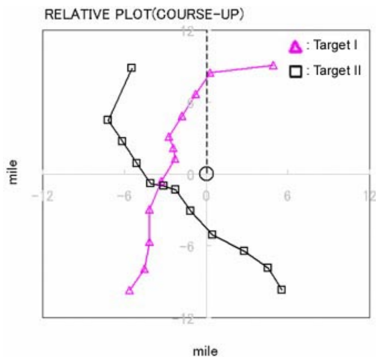

Figure 9 (b) Relative plot of Simulation result by applying the method for planning evasion route using OZT

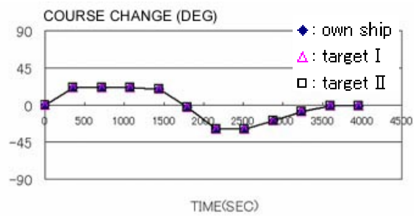

Figure 9 (c) Time series of ship's course change of simulation result by applying the method for planning evasion route using OZT

D. Consideration

The safety of the methods are confirmed, because all results of the simulation show the values of passing distance are over 0.5 mile set as the safety distance. In the case of the simulation of three ships' avoiding collision, the value by applying the method for planning evasion route using OZT is enormously large since for all of the three ships, the ships on their right became obstacles to returning their routes.

Concerning the values of maximum deviations from the route, the values applying the method of using lattice-like reference points are small in the case of the crossing situation and of the situation of avoiding three ships' collision, because the own ship waits for the target's passing by reducing its speed. In all simulation, the value of lost of advance by applying the method of using lattice-like reference points is large because the own ship avoids collision by reducing speed.

Also, the method for planning evasion route using OZT is considered to be easier to understand for watch officers since it is clear which side (forward side, back side and so on) of the target the own ship will pass to.

IV. CONCLUSION

We proposed a collision avoidance algorithm, that is, the method of using lattice-like reference points and the method for planning evasion route using OZT. Simulation results by applying these methods show the effectiveness of the fundamental functions. The algorithm provides feasible evasion route even in three ships' avoiding collision.

In this study, safe distance is set to a unified value. However, OZT makes more effective operation possible by setting safe distance separately where the ship passes the stern side of another ship and where it passes its bow side. We would like to reflect this to future studies.

Also, to apply these methods to active crew, it should be brushed up with expert's opinion.

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