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Control System for Ship Collision Avoidance considering the Effect of Wind and Ship's Manoeuvrability

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Abstract : *The studies on automatic ship collision avoidance system, which have been carried out in the last 10 years, are facing on new situation due to newly developed high technology such as computer and other information system. It was almost impossible to make it used in real navigation field 3-4 years ago because of the absence of any tool to give other ship's information, however recently developed technology suggests new possibility. This study is carried out to develop the automatic ship collision avoidance support system which considers ship's manoeuvrability into it's collision avoidance algorithm. One of the important part in ship collision avoidance system is collision decision module which can calculate collision risk with other ships and act properly to avoid the situation. Many of previous researches are using present ship's dynamic data such as present speed, position and course to calculate collision risk. However when a ship commences avoidance action, the real situation is quite different with one that has been estimated by the ship's initial data due to the ship's manoeuvring characteristic. Therefore it is better to take into account ship's manoeuvring characteristic from the stage of collision decision in ship collision avoidance system. In this study, these effects are included in the developed system. The proposed system are verified its usefulness in numerical simulation environments.*

Key words : *Fuzzy reasoning, Avoidance system, ship, automatic control*

1. Introduction

Recent rapidly developed IT(Intelligent Technology) is attracting our attention to the automatic navigation system such as track control system or AIS (Automatic Identification System) and so on. The collision avoidance system is one of those systems attracting the interesting of navigators and ship building companies. The study on collision avoidance system has been carried out by many researchers (Hasegawa, 1996; Hwang, 2002; Jeong, 2003) and these studies reached a new phase for theirs practical applicable study to be used in navigation. In these circumstances, it would be worth giving outline of the general feature and trying for improving the research. This study is carried out to develop the automatic ship collision avoidance support system which considers ship's manoeuvrability into it's collision avoidance algorithm.

One of the important part in ship collision avoidance system is collision decision module which can calculate collision risk with other ship's and act properly to avoid the situation. Many of previous researches have used present ship's dynamic data such as present speed, position and course to calculate collision risk. However when a ship commences avoidance action, the real situation is quite different with one that has been estimated by the ship's initial data due to the ship's manoeuvring characteristics.

Therefore it is better to take into account ship's manoeuvring characteristic in ship collision avoidance system from the initial stage of collision decision. In this study, these effects are included in the developed system. The proposed system are verified its usefulness in numerical simulation environments

2. Ship mathematic model

Ship's particulars used in simulation is shown in Table 1. MMG model is used for the mathematical model. Equations of the ship manoeuvering such as turn rate, speed and rudder operation can be written in Eq.(1). Ship's fixed coordinate system on the symmetry plane of the body is shown in Fig. 1.

$$(m+m_x)\dot{u}-(m+m_y)vr=X_H+X_P+X_R+X_W$$

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$$(m+m_y)\dot{v}+(m+m_x)ur+m_y\Delta_y\dot{r}-m_yl_y\dot{p} = Y_H+Y_P+Y_R+Y_W$$

$$(I_{xx}+J_{xx})\dot{p}-m_yl_y\dot{v}-m_xl_xur+w\overline{GM}\phi = L_H+L_P+L_R+L_W \tag{1}$$

$$(I_{zz}+J_{zz})\dot{r}+m_y\Delta_y\dot{v}=N_H+N_P+N_R+N_W$$

Where u,v,p.r : speed of surge and sway, angular velocity of roll and yaw. Suffix of H,P,R and W : hydrodynamic force of the hull, thrust, rudder and wind force.

Ship model used in this paper for simulation is container vessel with 1/58.1 of scale ratio. Table 1 shows the details of ship information.

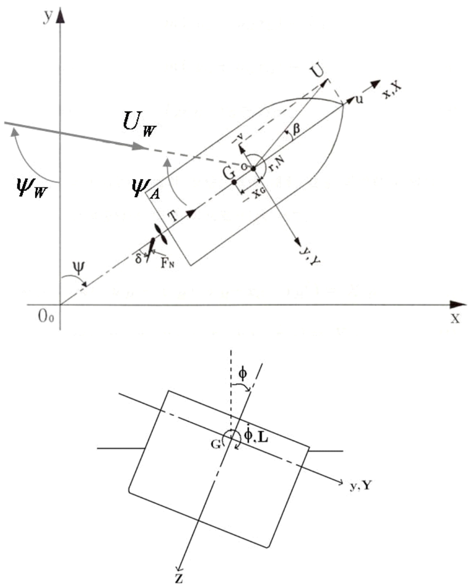

Fig. 1 The ship's coordinate

Table 1 Particulars of the ship

SR108	Ship	Model
Length B.P.(m)	175.0	3.0
Breadth (m)	25.4	0.435
Mean Draft (m)	8.5	0.146
Displacement Volume (m^3)	21222.0	0.10686
KM (m)	10.39	0.178
KB (m)	4.615	0.079
Block Coefficient	0.559	

In this paper, wind effect was considered to determine ship's avoidance action. Wind force model of Fujiwara (Fujiwara, 1998) was used. This model has been used many researches for its simplicity and convenience. The equation can be written as follows.

$$C_X=\frac{F_x}{qA_T}, C_Y=\frac{F_Y}{qA_L}$$

$$C_L=\frac{L}{qA_LH_L}, C_N=\frac{N}{qL_{OA}A_L}$$

$$q=0.5\rho_{air}U_W^2$$

$$H_L=\frac{A_L}{L_{OA}} \tag{2}$$

Where ρ_{air}, A_T, A_L : air density and lateral projected area. transverse of ship. The details are shown in Fig. 2.

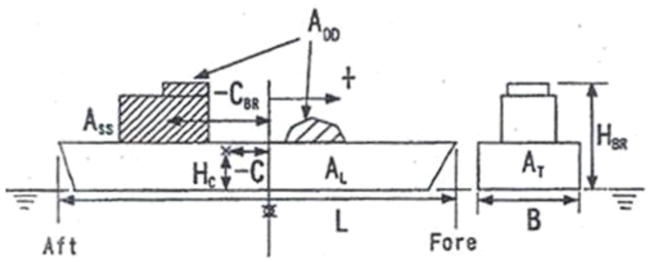

Fig. 2 Definition of parameters for ship wind area

3. Structure of system

Fig. 3 shows the flow of system developed in this study. The general concept is almost same with previous report (Im, 2005), however the difference is the effect of wind.

The first step is to obtain all information relating to ships such as speed, location and bearing and so on. In this stage, it is supposed that they come from Radar or AIS(Automatic Identification system). In second stage the collision risk is calculated based on other ship information. The TCPA(time to closest point of approach) and DCPA(Distance of CPA) are used as input variables. Many research(Hasegawa, 1987; Hasegawa, 1997) used the TCPA and DCPA as common factors for collision risk.

In third stage, ship's heading angle is determined to avoid dangerous ships with the index of collision risk calculated in the second stage, here wind effect are considered as shown in Fig. 3. A ship's motion can be changed after her avoiding action, due to external disturbance such as wind. Therefore this system includes wind effect module to consider ship's real motion under external disturbance.

Then heading control system is applied to this system to follow the suggested ship's heading angle. In final stage, the system checks the safety regarding to course return, where the wind effect is also considered to determine safe course.

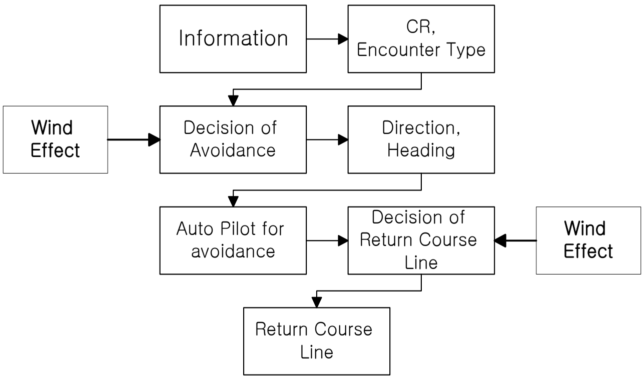

Fig. 3 Flow chart

4. The degree of collision risk

Many researches relating to ship collision avoidance system used an index number named CR (Collision Risk) to represent the degree of collision risk between ships. Generally the value of CR is set between 1 and + 1, the value of less than zero means no collision risk with other ships and as the risk of collision increase the value approaches to 1.

General collision avoidance algorithms are designed to take avoidance action when the CR exceeds the threshold value set by user. This study also used the CR value to evaluate the degree of collision risk. The time to the closest point of approach (TCPA) and distance of the closest point of approach (DCPA) are used as input variables to calculate the collision risk (CR) using fuzzy theory. The membership function for TCPA, DCPA and reasoning rules are quoted from other research(Hasegawa, 1987; Hasegawa, 1997). Fig. 4 and Table 2 show them respectively. Where the membership funtion are adjusted to make first avoidance action with the distance of 4-5 miles. This reflect the reality that navigations take avoidance action with the distance of 3-5 miles in the ocean sea. For the defuzzification, the center of area method is used.

Table 2 Reasoning rules for collision risk

		TCPA							
		SAN	MEN	DAN	DAP	DMP	MEP	SMP	SAP
DCPA	DA	SAN	MEN	DAN	DAP	DMP	MEP	SMP	SAP
	DM	SAN	SAN	MEN	DMP	MEP	SMP	SAP	SAP
	ME	SAN	SAN	SAN	MEP	SMP	SAP	SAP	SAP
	SM	SAN	SAN	SAN	SMP	SAP	SAP	SAP	SAP
	SA	SAN	SAN	SAN	SAP	SAP	SAP	SAP	SAP

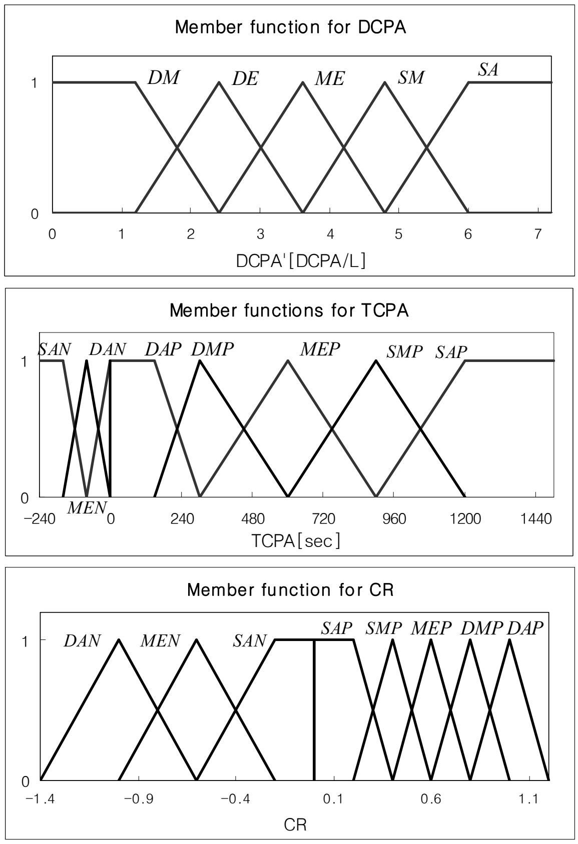

Fig. 4 Fuzzy membership functions

The PID control method is applied to keep ship's heading induced from collision avoidance algorithm. The PID method is one of control tool that are often used in control field due to their simple handling. PID means P: Proportion , I: Integral, D: Differential respectively. The expression of PID method can be written as equation 3.

$$U(t) = G_P e(t) + G_I \int e(t)dt + G_D \frac{de(t)}{dt} \tag{3}$$

where, e(t) is error , G_P, G_I, G_D are proportion gain, integral gain and differential gain respectively. In this study PD control only is applied in automatic pilot control system.

5. Collision avoidance algorithm considering wind effect

Generally, if a ship takes avoidance action toward certain course, the ship's speed and positions will be changed. In previous researches regarding ship's avoidance system, collision degree was calculated based on present own ship's position and speed. However as mentioned above, ship's position and speed are changed when the ship commenced avoidance action. The purpose of this research is to consider these phenomena into calculation of collision risk and avoidance heading angle. This concept can be written in Fig. 5 and Eq. 4.

$$CR_{Old} = f(x_O, y_O, U_O, \psi_O, x_i, U_i, \psi_i)$$
$$CR_{New} = f(x'_O, y'_O, U'_O, \psi'_O, x'_i, U_i, \psi_i) \quad (4)$$

Where CR_{Old}, CR_{New}: Collision risk calculated by old and new method.

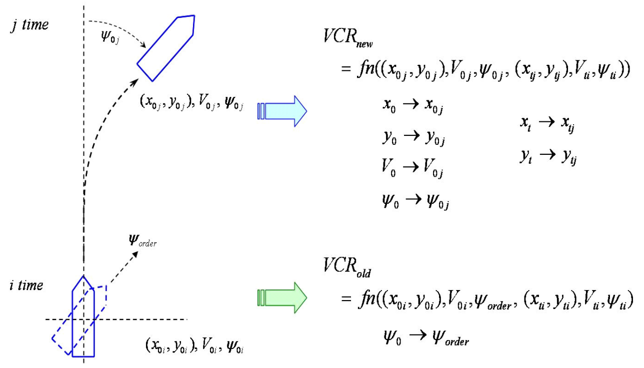

Fig. 5 New concept for collision degree

When a ship maneuvers, the speed and heading are affected by external disturbance such as wind acting on its hull. Simple numerical simulation is carried out to show the impact of wind on ship's motions. Fig. 6 shows simulation result with various wind directions. The ship's speed is set to 24kts with 35degree of rudder angle and 15m/s of wind velocity. As shown in this figure, the trajectories of ship changed from its original trajectories due to disturbance effect.

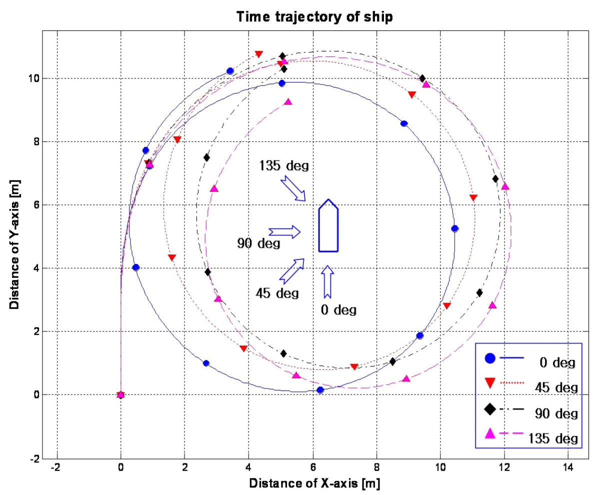

Fig. 6 Turning trajectories in wind

As mentioned above section, if a ship alters her course to certain angle, the position and speed would be changed according to her maneuvring characteristic. Therefore it is reasonable to use final ship's dynamic data for more correct collision risk. Moreover if the ship is effected by disturbance, it should be also considered in advanced. Some simulations are carried out to find ship motion effect. The results are shown in Fig. 7 and 8.

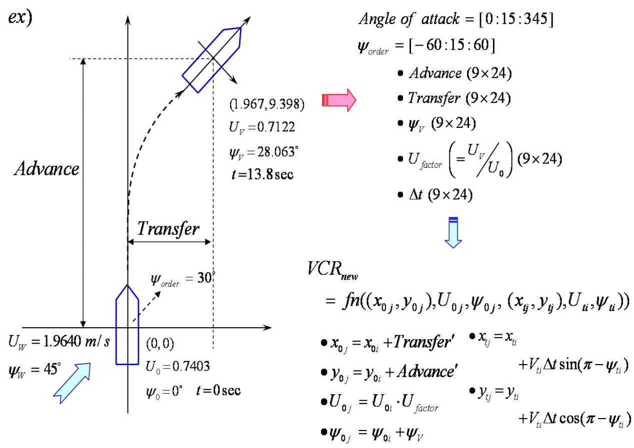

Fig. 7 Initial turning test

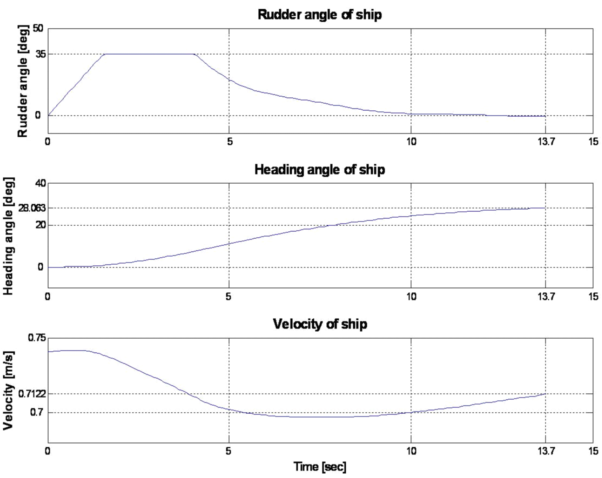

Fig. 8 Time histories of rudder, heading and speed

As shown in Fig. 7, moderate difference between initial and final positions are found. It is reasonable to use the ship data when the ship is located in final position. The simulation results show the gap between two points is like distance of "Advance" and "Transfer". The speed and heading at final point also can be adjusted by factors

6. Simulation results

The simulation conditions are as followings.

(1) Wind conditions

$$U_W = 1.964m/s(15m/s:30kts\ \ for\ real)$$

$$\psi_W = 45^{\circ}$$

(2) Model ship

$$U_O(OwnShip) = 0.7403m/s:1.5knots$$

$$(5.654m/s:11knots\ \ for\ real)$$

$$U_t(TargetShip) = U_O$$

(3) Encounter type : type 1 (encounter type)

(4) Collision Risk (CR)

$$CR_{SET} = 0.7$$
$$ACR_{SET} = 0.6$$
$$VCR_{SET} = 0.5$$

Fig.9 shows the comparison between the collision avoidance cases of wind load and no wind load. The DCPA is 41.2 m without wind load, however it became closer to 29.3m when wind load acts on the ship. It means that a ship get closer to passing ship than expectation under external disturbance effect.

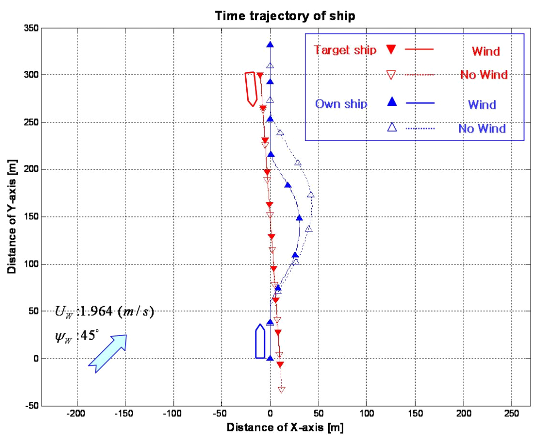

Fig. 9 Trajectories of own ship & target ship

In Fig. 10 the new method was adopted to avoid target under wind effect. The wind condition is set to 45deg and 1.964m/s of speed. The solid line indicates the trajectory of ship with new avoidance method. It shows more safe avoidance action comparing to old method. Time histories of own ship are shown in Fig. 11. It is found that the rudder angle of new method is more stable and have operated in advance.

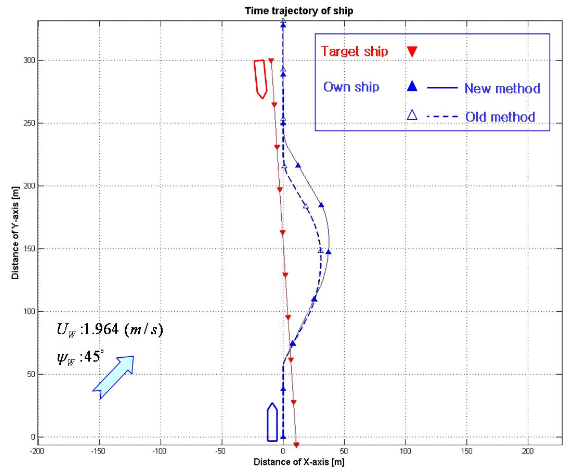

Fig. 10 Trajectories of own ship & target ship

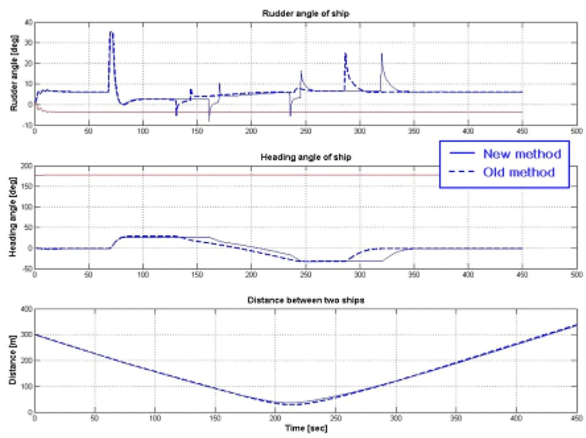

Fig. 11 Time histories for ship's data

7. Conclusion

The following can be summarized as main conclusions in this study.

(1) The ship avoidance algorithm was newly suggested to solve ship's manoeuvring characteristic using fuzzy controller under external disturbance effect.

(2) Ship's advance, transfer and speed change were included into ship's manoeuvring characteristic.

(3) Wind effect was considered as external disturbance effect.

(4) Various simulation case studies were carried out to verify the new algorithm.

In this study, reasonable results for collision avoidance algorithm could be obtained, however, in actual open sea navigators may take engine operations or other active action to avoid collision between ships. These would be one of further research items in ship collision avoidance study.

Acknowledgement

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Index 1. Language Variables
DA:Dangerious
DM;Mediumly Dangerious
ME:Medium
SM:Mediumly Safe
SA:Safe

SAN:Negative Safe
MEN: Negative Medium
DAN: Negative Dangerous
DAP:Positive Dangerous
DMP:Positive Mediumly Dangerous
MEP:Positive Medium
SMP:Positive Mediumly Safe
SAP:Positive Safe

CR: Collision Risk
TCPA:Time to the closest point of approach
DCPA:Distance of the closest point of approach

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