

Method of Safe Returning of the Vessel to Planned Route After Deviation from Collision

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ABSTRACT: Flexible strategies for collision avoidance, presented at TransNav 2007, were examined using computer program for its correctness in different situations of ships interaction. It was determined, that on short distance the risk of collision can arise again when the vessel returning to the planned route after deviation from collision. For controlling ship's safe returning, the mathematical model was developed. This model describes the analytical dependence of the rate of changing relative course with respect to rates of turning of the vessels and its initial relative position. This method can be used in automatic systems for controlling the safe returning of the vessel to the planned route.

1 INTRODUCTION

Flexible strategies for collision avoidance, take into account the presence of dangerous and obstacle vessels, hazards for navigation and the Colreg requirements. The strategy of collision avoidance depends on the realized range of mutual duties, relative position of vessel and target and, correlation of their speeds. In general strategy of deviation foresees transfer the current position of the vessel from subset of dangerous positions to subset of safe positions, calculation the deviation course and then returning to the planned route by a course tangent to the circle of the assigned CPA (Tsymbal 2006, 2007, 2008).

During modeling the flexible strategies on computer, it was determined, that on short distances the risk of collision can arise again when the vessel returning to the planned route after deviation from collision.

The paper presents the method for calculating the parameters for ship manoeuvring, when returning to the planned route after deviation from collision.

2 MATHEMATICAL MODEL

2.1 Three types of returning trajectories

The detailed analysis, shows that for safe returning of the vessel on the planned route in default of coordination between the ship and target it is necessary the initial situation G to identify with one of three subsets M_{n1} , M_{n2} or M_{n3} , each of which determines the type of trajectory for returning the ship and mathematical model for calculation the parameters of manoeuvre.

The first subset M_{n1} includes safe situations G , when are assured increase the distance L_t between the vessels and target, i.e. $dL_t/dt > 0$. Second subset M_{n2} includes situations, when distance between the ship and target reduces, i.e. $dL_t/dt < 0$. And, finally, the third subset of situations M_{n3} includes those situations, for which it is possible increasing or reducing the distance L_t .

For identification the type of initial situation G it is necessary to calculate the initial relative course K_{oto} and rate of its change ω_{otb} .

2.2 Calculation of relative course and rate of its change

The initial relative course K_{oto} means the relative course of the ship's deviation. Its calculation is produced on the parameters of motion of the vessel and target by expression:

$$K_{oto} = \arcsin\left[\frac{V_v \sin K_{vo} - V_c \sin K_{co}}{V_{oto}}\right]$$

where K_{vo} , V_v , K_{co} , and V_c , = the values of initial course and speed of the vessel and target accordingly; V_{oto} = initial relative speed:

$$V_{oto} = [V_v^2 + V_c^2 - 2 V_v V_c \cos(K_{vo} - K_{co})]^{1/2}$$

For calculation the value of relative angular speed ω_{otb} , it is necessary to know the values of rate of turn of the vessel ω_{vb} and the target ω_c .

Calculation of the value relative angular speed ω_{otb} for a situation, when the vessel and target change course simultaneously is produced by the following analytical expression:

$$\omega_{otb} = \frac{V_v \cos(K_{vt})\omega_{vb} - V_c \cos(K_{ct})\omega_c}{V_v \cos(K_{vt}) + V_c \cos(K_{ct})}$$

$$\frac{[V_v \sin(K_{vt}) - V_c \sin(K_{ct})]V_v V_c \sin(\Delta K_y + \Delta\omega_b t)\Delta\omega_b}{[V_v \cos(K_{vt}) + V_c \cos(K_{ct})]V_{ot}^2}$$

where $K_{vt} = (K_{vy} + \omega_{ybt})$; $K_{ct} = (K_{cy} + \omega_{ybt})$; $\Delta\omega_b = \omega_{yb} - \omega_c$; $\Delta K = K_{vy} - K_{cy}$; K_{vy} = vessel's course deviation; K_{cy} = target's course deviation. K_{vy} and K_{cy} determined previously by using the method of flexible strategies for collision avoidance.

When target keep her course, $\omega_c = 0$ and, only the vessel change her course

$$\omega_{otb} = \frac{V_v \cos(K_{vt})\omega_{vb}}{V_v \cos(K_{vt}) + V_c \cos(K_{cy})}$$

$$\frac{[V_v \sin(K_{vt}) - V_c \sin(K_{cy})]V_v V_c \sin(\Delta K_y + \omega_{yb} t)\omega_{yb}}{[V_v \cos(K_{vt}) + V_c \cos(K_{cy})]V_{ot}^2}$$

The sign of the vessel's rate of turn depends on the side of turn Δ_y , so, that $sign(\omega_{yb}) = -sign(\Delta_y)$; $\Delta_y=1$ when deviation to starboard.

2.3 Identification of initial situation

Belonging of the initial situation G to the subset M_{n1} is analytically expressed as follows:

$$G \in Mn_1, \text{ if } \{K_{oto} \in [\alpha_o + \pi/2, \alpha_o + \pi] \text{ and } \omega_{otb} > 0\},$$

$$\text{or } \{K_{oto} \in [\alpha_o + \pi, \alpha_o - \pi/2] \text{ and } \omega_{otb} < 0\};$$

$$sign(\omega_{vb}) = -sign(\Delta_y)$$

where α_o = initial bearing from the vessel to the target.

Condition which describes belonging of initial situation G to the subset M_{n2} , expressed by a next correlation of relative initial course K_{oto} and sign of rate of turn ω_{otb} :

$$G \in Mn_2, \text{ if } \{K_{oto} \in [\alpha_o - \pi/2, \alpha_o] \text{ and } \omega_{otb} > 0\}, \text{ or}$$

$$\{K_{oto} \in [\alpha_o, \alpha_o + \pi/2] \text{ and } \omega_{otb} < 0\};$$

$$sign(\omega_{vb}) = -sign(\Delta_y)$$

Belonging of initial situation G to subset M_{n3} , is determined by analytical expressions:

$$G \in Mn_3, \text{ if } \{K_{oto} \in [\alpha_o - \pi/2, \alpha_o] \text{ and } \omega_{otb} < 0\}, \text{ or}$$

$$\{K_{oto} \in [\alpha_o, \alpha_o + \pi/2] \text{ and } \omega_{otb} > 0\}, \text{ or}$$

$$\{K_{oto} \in [\alpha_o + \pi/2, \alpha_o + \pi] \text{ and } \omega_{otb} < 0\}, \text{ or}$$

$$\{K_{oto} \in [\alpha_o + \pi, \alpha_o - \pi/2] \text{ and } \omega_{otb} > 0\};$$

$$sign(\omega_{vb}) = -sign(\Delta_y)$$

The type of returning trajectory depends on the subset to which the initial situation belongs.

2.4 First type of returning trajectory

If G belonging to $Mn1$, the most preferable is the first type of vessel's returning trajectory to the planned route. This type of trajectory requires minimum time. The first type trajectory is shown on Figure 1.

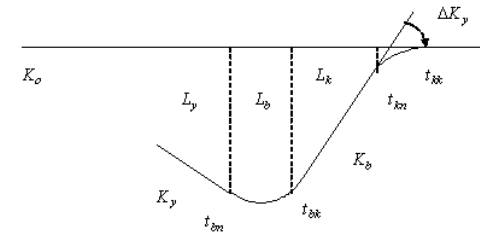


Figure 1. First type of returning trajectory in true motion

This manoeuvre includes the turn of vessel from the course of deviation K_y to the returning course K_b , and, when approaching to the planned route the vessel shall turn from the course K_b on a programmatic course K_0 , as shown on a Fig. 1 in true motion. The value of K_b depends on K_0 and ΔK_y . We proposed $\Delta K_y=40^\circ$.

The parameters of this manoeuvre are the values of: returning course K_b ; the moments of beginning the turn t_{bn} and ending the first turn t_{bk} ; the moments t_{kn} and t_{kk} – which determine the beginning end ending of the second turn. These parameters calculated by next equations:

$$L_k = R_c(1 - \cos \Delta K_y)$$

where $R_c =$ radius of circulation of the vessel.

$$\Delta t_{bn} = 2\Delta K_y / \omega_V$$

$$t_{bk} = t_{bn} + \Delta t_{bn}$$

$$L_b = \frac{(L_y - L_k)}{\sin \Delta K_y}$$

$$t_{kn} = t_{bk} + \frac{(L_y - L_k)}{V_v \sin \Delta K_y}$$

$$t_{kk} = t_{kn} + \Delta K_y / \omega_V$$

2.5 Second type of returning trajectory

In case when G belonging to M_{n2} , the vessel use second type of returning trajectory which consist with the first turn to the same side as deviation from collision with angular speed $\omega_{yb} = -\text{sign}(\Delta_y)\omega_{y\max}$ and, then returning to the planned route by course K_b . The second type of trajectory is shown on Figure 2 in true motion.

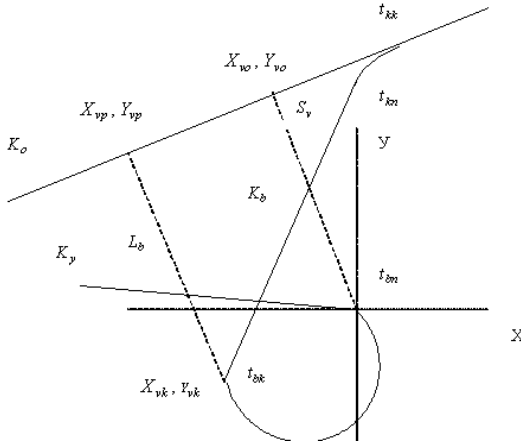


Figure 2. Second type of returning trajectory in true motion

On the first step it is necessary to determine the coordinates $X_{vo}, Y_{vo}, X_{vk}, Y_{vk}, X_{vp}, Y_{vp}$:

$$X_{vo} = -S_v \cos K_o$$

$$Y_{vo} = S_v \sin K_o$$

$$X_{vk} = R_c [\cos K_y - \cos(K_y - K_b)]$$

$$Y_{vk} = R_c [\sin(K_y - K_b) - \sin K_y]$$

$$X_{vp} = \frac{\cos K_o [X_{vo} \cos K_o + (Y_{vk} - Y_{vo}) \sin K_o]}{(\cos^2 K_o - \sin^2 K_o)}$$

$$Y_{vp} = [Y_{vo} \sin K_o + (X_{vp} - X_{vo}) \cos K_o] / \sin K_o$$

Then we calculate the distance L_b :

$$L_b = \sqrt{(X_{vp} - X_{vk})^2 + (Y_{vp} - Y_{vk})^2}$$

The parameters of manoeuvre calculated by next equations:

$$t_{bk} = t_{bn} + [2\pi - (K_y - K_b)] / \omega_V$$

$$t_{kn} = t_{bk} + \frac{(L_b - L_k)}{V_v \sin \Delta K_y}$$

$$t_{kk} = t_{kn} + (K_b - K_o) / \omega_V$$

2.6 Third type of returning trajectory

If G belonging to M_{n3} , the vessel shall continue motion with relative course of deviation K_{oty} till the moment, when the returning to relative course K_{otb} guarantee that CPA will not less then L_d . This third type of returning trajectory shown on Figure 3 in relative motion.

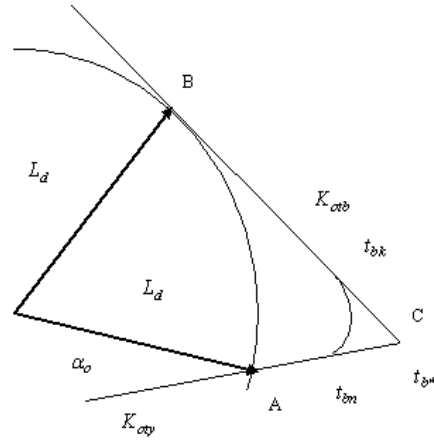


Figure 3. Third type of returning trajectory in relative motion

In the beginning it is necessary to calculate the co-ordinates of points A,B,C:

$$X_A = L_d \sin \alpha_o$$

$$Y_A = L_d \cos \alpha_o$$

$$X_B = L_d \cos K_{otb}$$

$$Y_B = -L_d \sin K_{otb}$$

where $K_{otb} =$ relative course of returning.

$$Y_C = \frac{G}{(\text{tg} K_{oty} - \text{tg} K_{otb})}$$

$$X_C = X_B + \left[\frac{G}{(\text{tg} K_{oty} - \text{tg} K_{otb})} - Y_B \right] \text{tg} K_{otb}$$

where

$$G = X_B - X_A + Y_A \text{tg} K_{oty} - Y_B \text{tg} K_{otb}$$

$K_{oty} =$ relative course of deviation.

Distance L_{AC} between points A and C calculated as follows:

$$L_{AC} = \sqrt{(X_C - X_A)^2 + (Y_C - Y_A)^2}$$

The moment of time to turn t_{b*} is determined by the following formula:

$$t_{b*} = \frac{L_{AC}}{V_{oy}} = \frac{\sqrt{(X_C - X_A)^2 + (Y_C - Y_A)^2}}{V_{oy}}$$

Amendment for ship's dynamic Δt_b is calculated on a formula:

$$\Delta t_b = \{ \sin K_{otb} R_c (\sin K_b - \sin K_y) - \cos K_{otb} R_c (\cos K_y - \cos K_b) + V_c \tau \sin (K_{otb} - K_c) \} / [V_{oy} \sin (K_{oty} - K_{otb})]$$

$$\tau = \frac{Abs(K_b - K_y)}{\omega_{vb}}$$

where

The parameters of beginning and ending the turn to course K_b are calculated by next equations:

$$t_{bn} = t_{b*} - \Delta t_b$$

$$t_{bk} = t_{bn} + \tau$$

3 EXPERIMENTS AND RESULTS

For verification of correctness theoretical results the imitation software was designed for modeling the manoeuvre of returning the vessel to the programmatic trajectory of motion in different situations and with different types of returning trajectory. This computer program allows on the set initial situation choose the safe manoeuvre of returning and builds his trajectory on the screen. Information appears in relative and true motion.

On Figure 4 a situation is shown, when the safe manoeuvre of returning is possible by the trajectory of the first type.

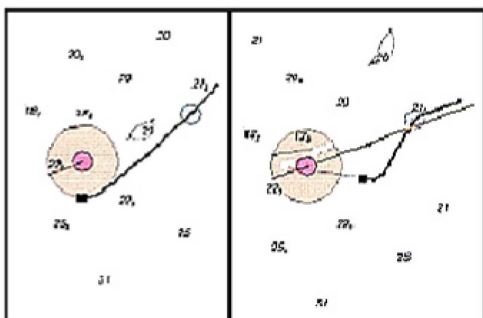


Figure 4. First type trajectory for safe returning

Left part of screen shows the relative trajectory of the vessel in relation to the immobile target. Right part of the screen contains the trajectories of the vessel and target in true motion. As we can see, on relative motion, the distance between vessel and target is increasing. Black square shows the initial position of the vessel after deviation from collision.

On Figure 5 second type of safe returning trajectory shown.

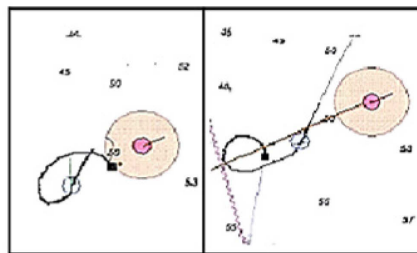


Figure 5. Second type trajectory for safe returning

Third type of safe returning trajectory shown on Figure 6.

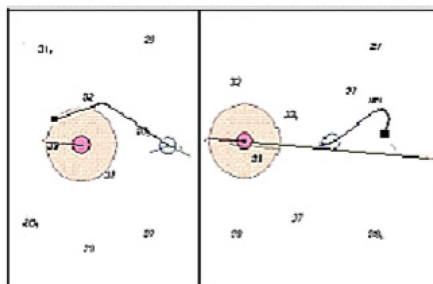


Figure 6. Third type of safe returning trajectory

More than 100 different initial situations were generated and the parameters of manoeuvres of returning on the programmatic trajectory of motion are calculated and modelling. It appeared that 51% of manoeuvres had the first type of trajectory of returning, 37% is the second type and 12% is the third type. All manoeuvres chosen by the program were safe.

4 CONCLUSION

This paper presented the method which taking into account high level of vagueness of target's conduct, and increase safe returning of the vessel to planned route after deviation from collision.

Obviously, that at presence of co-ordination between a vessel and target on the stage of their returning to planned route provides more high safety returning.

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