SELECTION OF EFFECTIVE AND COST-EFFECTIVE OPTIONS FOR CHANGING THE VESSEL'S COURSE, TAKING INTO ACCOUNT NAVIGATION CONDITIONS

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გემის კურსის შეცვლის ეფექტური და ეკონომიური ვარიანტების შერჩევა ნავიგაციის პიროგების გათვალისწინებით

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რეზიუმე

გემების შეჯახების თავიდან აცილების საერთაშორისო რეგულაციების (COLREG-72) შესაბამისად, როდესაც გემებს შორის შეჯახების საშიშროება წარმოიქმნება, საჭიროა სწრაფი და გადამწყვეტი ზომების მიღება მისი თავიდან აცილების მიზნით. უმეტეს შემთხვევაში ეს ხდება გემის კურსის და/ან სიჩქარის ცვლილებით. ამასთანავე გასათვალისწინებელია ისიც, რომ კურსისა და/ან სიჩქარეში მცირე ცვლილებები ხშირად არაეფექტურია. ამიტომ გემის მანევრირების შერჩევა შეჯახების პრევენციის მიზნით ყოველთვის აქტუალურია.

კვლევის მიზანია შემუშავდეს გემის ნავიგაციის ავტომატური რეჟიმისთვის ალგორითმი, რომელიც იძლევა მარშრუტის სწრაფი კორექტირების საშუალებას, რათა თავიდან ავიცილოთ გემებთან და დაბრკოლებებთან საშიშ მანძილზე მიახლოვება.

მარშრუტის ოპერატიული კორექტირებისთვის შემოთავაზებულია ორი მეთოდი: აქტიური კურსის მონაკვეთის პარალელური გადაადგილება და სავალი წერტილის დასმა.

შემოთავაზებული მეთოდების ეფექტურობის შესამოწმებლად შემუშავდა გემის ნავიგაციის სიმულაციური მოდელი მოცემული ტრაექტორიით მოძრავი სამიზნეებით, ზემოთ განხილული მეთოდის გამოყენებით შესაძლებელი გახდა მარშრუტის სწრაფი კორექტირება. ამ პროგრამის გამოყენებით სიტუაციის ანალიზმა აჩვენა, რომ შემოთავაზებული მეთოდები იძლევა გემის მარშრუტის კორექტირების ეფექტური ვარიანტების არჩევის საშუალებას ნავიგაციის საფრთხის არსებობის გათვალისწინებით. დაბრკოლების გვერდის ავლის მანევრის შერჩევა და მისი შესრულება ხორციელდება ავტომატურად და არ საჭიროებს გემის გადაყვანას ხელოვნური მართვის რეჟიმში..

საკვანძო სიტყვები: გემი, კურსი, დაბრკოლება, მანევრი, ნავიგაცია.

SUMMARY

According to the International Regulations for Preventing Collisions (COLREG 1972), when there is a risk of collision between vessels, early and decisive action must be taken to avoid it. Any change of course and/or speed must be significant enough to be readily observed by other vessels and must be in accordance with good seamanship. A series of small changes of course or speed should be avoided as they may be ineffective.

The problem of choosing maneuvers to prevent collisions of vessels always remains relevant. The aim of the study is to develop algorithms for the automatic mode of vessel navigation along a given route that allow promptly adjusting the route of passage to prevent excessive proximity to vessels and obstacles, assessing the safety of movement along the changed route and choosing an effective route correction option. Two methods are proposed for prompt route correction: parallel displacement of the active section of the route and insertion of a waypoint. To test the effectiveness of the proposed methods, a simulation model of vessel navigation along a given trajectory in the presence of moving targets was compiled, allowing promptly adjusting the route in the manner discussed above to pass the targets. Analysis of many divergence situations using this program showed that the proposed methods provide an easy way to select effective route correction options for passing several vessels and allow taking into account the presence of navigational hazards in the area of movement. The choice of the divergence maneuver and its execution are made in the automatic vessel navigation mode along the route and do not require switching to manual vessel control mode.

Keywords: Vessel, Course, Obstacle, Maneuver, Navigation.

A large number of works are devoted to the problem of choosing maneuvers to prevent collisions of vessels. Their results are reflected to a certain extent in publications [1, 3, 4]. Currently, multipurpose systems for route planning, situation assessment and vessel navigation are being developed for vessels. In them, the vessel is controlled by a navigation and information system (NIS). In the control mode, it should allow promptly and easily adjusting the planned route of passage on the electronic card (EC) to avoid a collision with an obstacle or a vessel, simply assessing the effectiveness of the planned measures based on the image on the EC, activating them from the EC module, and monitoring the process of vessel movement along the changed route. The purpose of the study is to develop algorithms for the automatic mode of vessel navigation along a given route that allow, in the dialogue mode with the NIS on the electronic map, promptly adjusting the route of passage to prevent excessive proximity to vessels and obstacles, assessing the safety of movement along the changed route and choosing an effective route correction option.

For operational route correction, two methods are proposed:

parallel shift of the active route segment and waypoint insertion.

In many situations, to prevent excessive proximity to other vessels, it is advisable to shift to a parallel track line (SPRL) [2]. This standard maneuver can be used with a deviation angle from the course of up to 150°.

The trajectory of the vessel's CM during the maneuver is shown in Fig. 1. This maneuver is characterized by: the angle of course change ΔK , a given turning parameter (let's say radius R3), the turn time τ by the angle ΔK and the distance traveled during this time Δl , the distances Δs , Δb from the waypoint Z to the start points A and end points B of the turn, the length SL of the straight segment, the direct cm s and lateral r_{cm} displacement of the end point E relative to the initial A, the duration mτ of the maneuver and the moment mt of its beginning.

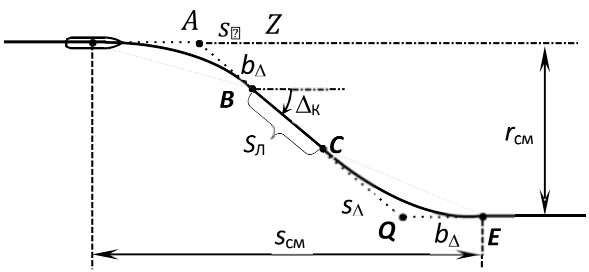

Fig. 1. Maneuver of shifting to a parallel track line

Depending on the given radius *R3* and the angle of rotation, the values of Δs and Δb can be calculated using simplified form (ulus explained in Fig. 2:

$$S_\Delta=(R_3+K_{R3}L)tg\frac{\Delta_K}{2}; \quad b_\Delta = tg\frac{\Delta_K}{2}$$

Here *L* is the length of the vessel; Rз, k is the coefficient corresponding to a specific vessel (usually lies in the range from 0.7 to 1.7, on average it is considered equal to one). Thus, the turning trajectory is simplified as a set of the turning delay section AP and the arc of a circle PB. The length of the turning trajectory

$$l_\Delta = K_{R3}L * tg\frac{\Delta_K}{2} + R_3\,\Delta_K$$

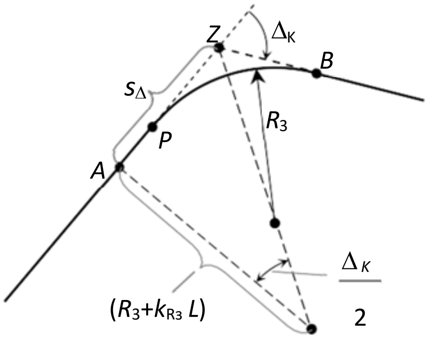

Fig. 2. Maneuver parameters S_Δ; b_Δ

More precisely, the maneuver parameters $S_\Delta,\ b_\Delta,\ l_\Delta$ are found by modeling

in accelerated turn time using the reference model of the automatic course control system. The turn time by an angle Δ_K and the duration of the maneuver are calculated using the formulas:

$$\tau_{turn} = \frac{l_\Delta}{V} \ ; \tau_m = \ 2\tau_{turn} + S_l/V$$

In some cases, the transition route is represented as a broken line with circular areas of radius $S_\Delta = f(R_{3,}\ \Delta_K)$ near the waypoints (Fig. 4). These areas, on the boundary of which the turn begins, are called zones of evolutionary motion.

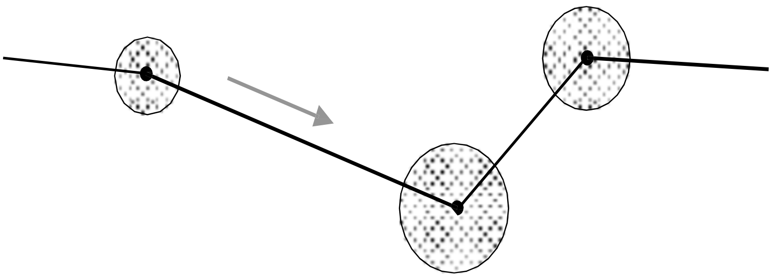

Fig. 3. Route with zones of evolutionary movement

In order to avoid excessive approach to vessels by shifting to a parallel track line in the route section [J-1, J] mode (Fig. 4), the deviation angle from the course (ΔK) and the shift (r_{cm}) of the remaining part of the active track section are set without changing its direction. As a result, two new waypoints (Z, Q) are entered into the route and the position of the turning point J is changed.

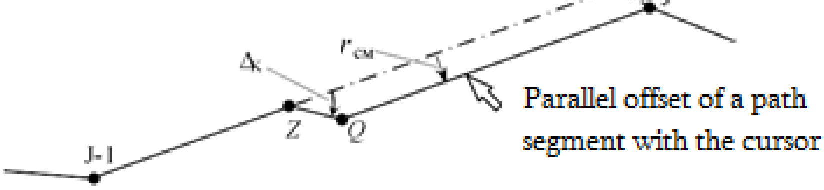

Fig. 4. Changing the route to pass a vessel by maneuvering to a parallel track line

Point Z is usually considered to be a location at a distance S_Δ ahead of the current position of the ships. If the start of the maneuver is planned with a time delay (t), then the future position of the ship's CM at a distance of $(S_\Delta + V * t)$ from its current location is taken as Z. The position of waypoints Q, J depends on Δ_k , r_{cm} as well as the courses along the active and following segments of the route.

In order to promptly change the route using the method under consideration, it is necessary to introduce a special function and a program for its implementation into the R/V. This program should allow assigning , $R_{3,}$ Δ_K and the shift r_{cm} of the route segment. It is also advisable to provide for the input of the delay time tзд of the maneuver.

It is convenient to shift the active route segment by "dragging" it with the cursor while holding down the left button of the manipulator. When performing this operation, it is necessary to calculate the values of the parameters of the SPLP maneuver (in the area of its existence) corresponding to the shift r_{cm} of the route segment. The following should be displayed on the screen:

the forecast of the vessel's route and its position calculated at the end of the maneuver with the speed vector and safety area; target vessels, their path from the current location to the one predicted at the end of the maneuver, the vectors of true and relative motion.

Fig. 5 - 7 shows an example of data display when selecting a maneuver of the SPLP to diverge from 4 targets. The initial situation is shown in Fig. 5. The time of the true motion vectors is taken to be 6 min, the relative motion vectors - 12 minutes, the maneuver delay time - 0 min. The permissible closest approach distance (PCAD) is set to 10 kb.

When selecting a maneuver (Fig. 6), the predicted trajectory of our vessel's transition to the active route segment shifted by the cursor is shown by a dotted line. Near the vessel's predicted location at the end of the SPLP maneuver, its speed vector and safety zone with the PCAD radius are shown by a solid line.

The actual position of the target in Fig. 6 is designated by its number. The true and relative motion vectors are shown near the predicted target location at the end of the maneuver. If the target is not dangerous at the end of the maneuver, the true motion vector will be a thin solid line, and the relative motion vector will be a thin dotted line. If the target is dangerous, the true motion vector will be a thick solid line, and the relative motion vector will be a thick dashed line. If there is no excessive approach to the target in the interval from the beginning to the end of the maneuver, the path from the actual position to the predicted position at the end of the maneuver is shown as a thin dashed line. If a dangerous approach occurs in the named time interval, this path is displayed as a "dash-two dots" line. The given method of data display is chosen for explanations. On the NIS monitor screen, to improve understanding of the situation, information is highlighted in more effective ways: different colors, blinking, etc.

The choice of the divergence maneuver consists in finding (by shifting the cursor to the right and left of the route segment relative to its initial position) the smallest r_{cm}, at which the SPLP maneuver does not contradict the COLREGs and does not lead to the danger of excessive rapprochement with other vessels during the evasion process and at the moment of its completion. In the example under consideration, such a shift (r_{cm} = 16.62 kb) is shown in Fig. 6. Having selected r_{cm}, the navigator, depending on the situation, determines the maneuver start point. When the vessel arrives at it, gives the command to begin movement along the changed route. According to this command, waypoints Z, Q, J, corresponding to the selected r_{cm} value, are entered into the planned route in the research vessel. The research vessel, ensuring movement along the changed route, will perform the divergence task. The situation of vessel rapprochement at the moment of entering the shifted route segment is shown in Fig. 7.

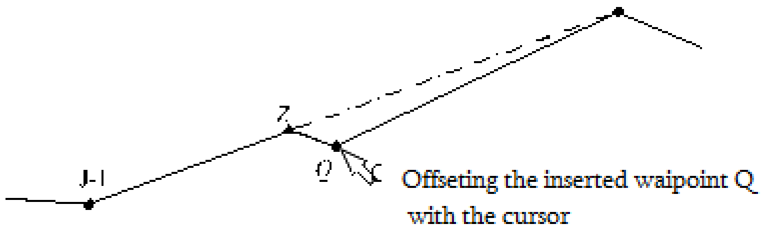

Fig. 8. Changing the route to avoid a vessel by inserting a waypoint Q

The second proposed method for selecting a change in the trajectory for diverging from ships corresponds to the insertion of two waypoints Z and Q (Fig. 8). Point Q appears when the manipulator key is pressed in the mode of selecting a divergence maneuver in this way. Its location coincides with the cursor position. When the key is pressed, point Q can be dragged by the cursor along the EC field. Point Z appears when Q is displayed. The location of Z is determined by the position of our vessel, point Q, and the assigned maneuver delay time. For any position of point Q selected by the cursor, it is possible to view (in the area of existence of the maneuver) what the situation of the convergence of the vessels will be at the moment our vessel enters the QJ segment and what the amount of loss of running time will be.

To test the efficiency of the proposed methods, a simulation model of vessel navigation along a given trajectory in the presence of moving targets (up to 50) was developed, allowing the route to be promptly adjusted in the manner discussed above in order to pass the targets. Analysis of many divergence situations using this program showed that the proposed methods provide ease of selection of effective route adjustment options for passing several vessels and allow the presence of navigational hazards in the area of movement to be taken into account. The selection of the divergence maneuver and its execution are performed in the automatic vessel navigation mode along the route and do not require switching to manual vessel control mode.

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