THE USE OF THE RISK CRITERION IN THE TASK OF OPTIMIZATION OF SHIP DIVERGENCE TRAJECTORIES

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Introduction. The problem of researching effective methods for preventing collisions of ships has become paramount and important in connection with the increase in tonnage, overall dimensions, speed and number of ships involved in the carriage of goods by sea. An obvious contribution to improving the safety of navigation was, firstly, the use of radars, and then the development of the ARPA (Automatic Radar Plotting Aids) collision avoidance system, which allows you to automatically track at least 20 encountered "n" objects, determine the parameters of their movement (speed V_n, course Ψ_n) and elements of approach to own ship (($D^n{}_{\min} = DCPA_n$ - distance to the closest point of approach (Distance of the Closest Point of Approach), $T^n{}_{\min} = TCPA_n$ - time to the closest point of approach, (Time to the Closest Point of Approach)) and collision risk assessment r_n.) and elements of approach to own ship ((- distance to the closest point of approach), - time to the closest point of approach, (Time to the Closest Point of Approach)), as well as collision risk assessment.

There are various methods for preventing ship collisions. The simplest method is to use own ship's course or speed change maneuver in relation to the most dangerous oncoming ship or ships in the zone of close proximity. A more efficient method is to determine the safe trajectory of the vessel.

The task of ensuring safety when maneuvering several ships is quite complex and is associated with the formation of decision criteria when plotting a course. The existing methods for solving the problem of safe separation of ships are based on the criterion of absolute safety. This approach provides solutions to ensure that there is no dangerous encounter, but ship collisions do occur and there is confidence that the "absolutely" safe trajectory contains the likelihood of collision. It is more rational to use the risk field when constructing the trajectory. The main advantage of this approach is taking into account the distribution of risks in the vicinity of the target. Taking a normal distribution and highlighting an ellipse of equal risk, accompanying the goal, the tasks of visualizing the risk field and critical trajectories are easily formed, trajectory construction that ensures that the specified risk is not exceeded with a minimum divergence maneuver path. However, it should be noted that the algorithm is focused on modern computing systems and operates with fields - large arrays of numbers. This feature allows you to operate at once with the entire scene of the operation and raise the question of the optimal solution of the entire operation for all participants. The optimality of the trajectory, within the framework of this approach, is formed as not exceeding a given risk with a minimal maneuver path. In this case, the risk field contains the risk of ambiguity of the target trajectories, which ensures the prompt rebuilding of the trajectory in case of disturbances in the target's behavior. It is essential that the use of the risk function ensures that instrumental errors are taken into account when measuring target parameters. For modern computing systems, the method is programmed simply, which is confirmed by the given text of the simulation program.

Relevance of research. A more efficient method is to determine the safe trajectory of the vessel. The task of ensuring safety when maneuvering several vessels is quite complex and is associated with the formation of decision criteria when plotting a course. It is more rational to use the risk field when constructing the trajectory. The main advantage of this approach is taking into account the distribution of risks in the vicinity of the target. Naturally, taking a normal distribution and highlighting an ellipse of equal risk, accompanying the goal, it is easy to form the task of visualizing the risk field and critical trajectories, constructing a trajectory that ensures that a given risk is not exceeded with a minimum divergence maneuver path. However, it should be noted that the algorithm is focused on modern computing systems and operates with fields - large arrays of numbers. This feature allows you to operate at once with the entire scene of the operation and raise the question of the optimal solution of the entire operation for all participants. The optimality of the trajectory, within the framework of this approach, is formed as not exceeding a given risk with a minimal maneuver path. In this case, the risk field contains the risk of ambiguity of the target trajectories, which ensures the prompt rebuilding of the trajectory in the event of disturbances in the target's behavior.

Therefore, the development of methods for the optimal divergence of ships using risk fields is an urgent scientific and technical task.

Problem statement. An integral function of the total risk is given, depending on the trajectory of own ship $L(\mathbf{x}(t))$ in case of discrepancy

$$\overline{C}(\mathbf{x}) = \frac{C_m}{2\pi\sigma_x\sigma_y} \int_{L(t)} e^{-\frac{1}{2-2r_{xy}}\left[\frac{(v_x t - x_0)^2}{\sigma_x^2} - \frac{r_{xy}(v_x t - x_0)(v_y t - y_0)}{\sigma^2{}_x \sigma^2{}_y} + \frac{(v_y t - y_0)^2}{\sigma_y^2}\right]} dt \tag{1}$$

It is required to find an optimal trajectory $L^*(\mathbf{x}(t))$, that would minimize the integral function of the total risk (1)

$$L^*(\mathbf{x}(t)) \to \min \overline{C}$$

Research results. For a situation of several goals in the problem of divergence of ships, we single out ships whose trajectory $f(t)$ leads to collisions with the trajectory of own ship $f_0(t)$ - critical trajectories and trajectories $f^*(t)$ that do not cause the danger of collision, Fig. 1.

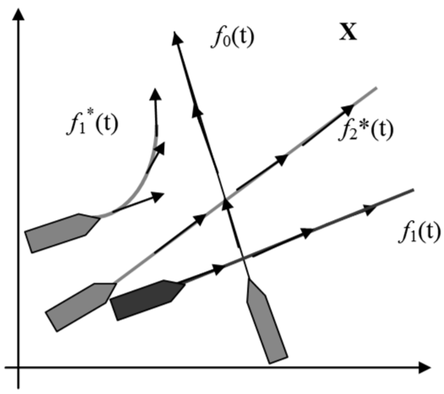

Figure 1 – The group of trajectories in the divergence task

To construct the expected trajectories, fig. 1, it is possible for the moment t_0 and further continuation is only the hypothesis of the development of the situation. We will strive to determine the trajectories of the targets for the duration of the divergence. For this it is possible to use statistics or information from the courts participating in the discrepancy. In this case, the main source of assessing the situation is radar assessment. By the end of the divergence we mean the moment when all trajectories are known exactly and there are no critical trajectories for all ships participating in the operation.

After identifying critical trajectories, the standard problem of divergence of ships with a known critical trajectory and constraints presented in the form of a set of non-critical trajectories is solved. Considering the set of divergence algorithms [2], we note that almost all of these algorithms are constructed as optimization problems, where the objective function is either to estimate the distance between ships or the divergence time [3 -5]. One of the fundamental elements in the theory of ship collision avoidance is the concept of the ship domain [6]. Here the task of unconditional provision of the ship's safety is solved in the absence of accurate information about the strategy of the targets involved in the operation. Suppose that there is a maximum penalty for collision of ships $C_{\max}$. Since we have many insignificant and independent of each other causes of collision, it is advisable to take this penalty as a normal distribution of risk [7-9]. The bivariate normal risk distribution can be represented as:

$$f\left(\overset{\circ}{\mathbf{x}}\right) = \frac{\alpha}{\pi \sigma_x \sigma_y} \exp\left(-\alpha \overset{\circ T}{\mathbf{x}} S \overset{\circ}{\mathbf{x}}\right). \tag{2}$$

Expression (2) allows to construct a risk field for the discrepancy task in the presence of uncertainties. It is very convenient to assess risks using the three sigma rule. So for a rendezvous less than 3σ, the collision probability is 0.997, which quite accurately determines the boundaries of the ship's contour in the task of divergence. At the same time, it is easy to determine the assessment of the risk of convergence of goals simply by adding their risks so for two goals with risks $C_{\max 1}$ and $C_{\max 2}$ we obtain an analytical form of risk assessment

$$\boldsymbol{C}(\mathbf{x}) = \boldsymbol{C}_{\max 1} f_1\left(\overset{\circ}{\mathbf{x}}\right) + \boldsymbol{C}_{\max 2} f_2\left(\overset{\circ}{\mathbf{x}}\right) \tag{3}$$

Distribution (3) determines the risk assessment for the case of divergence of two ships. This makes it possible to use gradient procedures to solve the task of finding the optimal trajectory. Thus, a risk field is formed, Fig. 2 and it becomes possible to consider the formation of the target function for the optimization problem of divergence of ships.

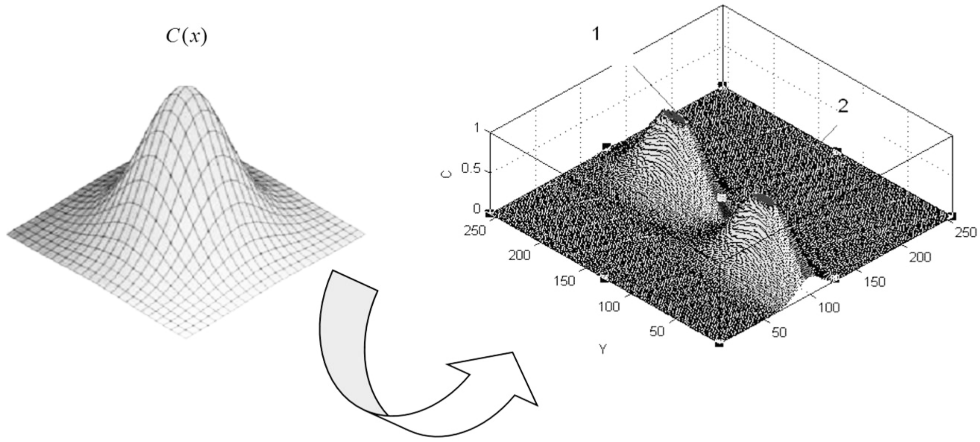

Figure 2 – Formation of the risk field in the problem of divergence of ships

Let us consider an example of the formation of a critical region field for the task of divergence of two goals. In the risk field of the problem, select lines of equal risk level and use arrows to designate the gradients of the risk field, Fig. 3.

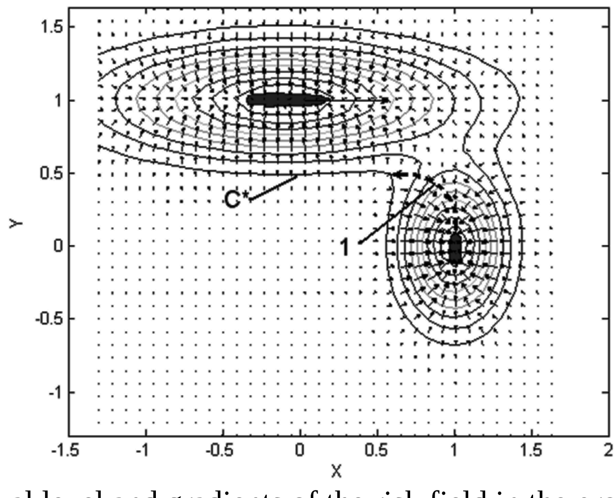

Figure 3 – Lines of equal level and gradients of the risk field in the problem of divergence of

goals

Mathematically, this task is solved as follows. Since the line of a given risk is a line of equal level for the second goal, it is sufficient to maintain a course perpendicular to the gradient field of the risk function of the second goal, taking membership in this line as a limitation. Here, the use of a broken line used for manual plotting is ineffective and implies automatic control of the vessel.

Figure 4 shows the result of modeling in MATLAB the discrepancy along the optimal sliding trajectory - the line of a given risk [10, 11].

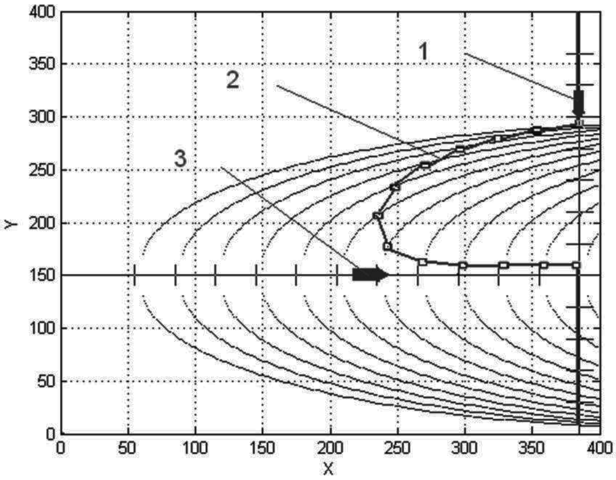

Figure 4 – Trajectory of sliding along the line of a given risk in the problem of divergence of ships

Conclusion. The above results of the study allow us to believe that the method for solving the task of divergence of ships using the field of expected risks provides: optimal trajectories of movement without exceeding the specified risk and minimality of the maneuver path, visualization of the navigation situation, simplicity of the calculation algorithm. In general, the considered algorithm is focused on "machine" methods of calculation, but it is also possible to use manual laying in the presence of a constructed risk field. The given simulation results and the simulation program make it possible to estimate the complexity of the method. The considered method for solving the problem allows us to set the task of taking into account the dynamic characteristics of ships and opens up the possibility of setting the problem of ensuring optimality for all participants in the operation.

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