APPLICATION OF THE METHOD OF RESETTING THE KINETIC ENERGY OF THE COLLISION ALONG THE GRADIENT

Zinchenko S.M., Kyrychenko K.V., Grosheva O.O., Polishchuk V.O
Kherson State Maritime Academy
(Ukraine)

Introduction. The number of maritime transports only increases over the years, which causes an increase in maritime transport accidents. As statistics show, most accidents on sea transport occur precisely because of the human factor. The paper [1] reviews the latest advances in vessel collision risk assessment. The review revealed a wide and diverse range of techniques, including machine learning, clustering techniques, and others. In [2], the problem of local route planning in a complex dynamic environment with several vessels is solved. An autonomous collision avoidance system based on deep The system switches between path tracking and collision avoidance modes in real-time, during which any danger of collision is perceived through collision identification and risk calculation. The simulation is performed under multi-vessel collision conditions, taking into account the vessels hydrodynamic model, environmental disturbance model, COLREG and good seaman vessel. The issue of reducing damages in case of inevitable collision of vessels was also considered in the previous works of the authors [3, 4]. It is difficult for a person in a stressful situation to make the right decision due to the emotional factor and time constraints. Therefore, the task of developing automatic control of vessels to prevent vessel collisions is becoming more and more urgent [5-23]. In this case, a person only decides to activate the automatic control mode and observes its operation.

Relevance of research. The analysis of literary sources showed that such questions had not been considered before. Therefore, the development of methods, algorithmic and software of automatic modules for controlling the movement of vessels in cases of imminent collision is an urgent scientific and technical task.

Formulation of the problem. In order to minimize the kinetic energy of the collision between the vessel and the target in the event that it is impossible to avoid this collision, it is necessary to develop a method, algorithm and software of the automatic control module of the automated system.

Research results. The own vessel O_1 moves on a course φ_1 with speed V_1, the target vessel O_2 moves on a course φ_2 with speed V_2. Vessels move on courses that intersect at a point O and are at a distance where collision cannot be avoided.

The idea of the method is to organize the fastest reduction of kinetic energy (4) along the gradient in the direction of the minimum value $K = 0$ by calculating the relevant movement parameters V_1, φ_1 and their subsequent implementation by means of the control system.

The kinetic energy gradient of the collision of two vessels is written in the form

$$\frac{dK}{dt} = \frac{\partial K}{\partial V_1}\frac{\partial V_1}{\partial t} + \frac{\partial K}{\partial \varphi_1}\frac{\partial \varphi_1}{\partial t} = < \mathbf{grad}K, \frac{d\mathbf{P}}{dt} >, \quad (1)$$

For the fastest reset of the kinetic energy of the collision, it is necessary to minimize the function (1)

$$< \mathbf{grad}K, \frac{d\mathbf{P}}{dt} > \to \min \quad (2)$$

The vector $\mathbf{grad}K$ indicates the direction of the fastest release of kinetic energy in the state space $V_1 - \varphi_1$, and a vector $\frac{d\mathbf{P}}{dt}$ indicates the real direction of change of movement parameters and is determined by the mathematical model of the vessel-target system. The vector $\frac{d\mathbf{P}}{dt}$ depends on the control parameters Θ and δ, and the minimization of function (2) is achieved by proper selection of control parameters from the admissible domain.

$$|\Theta| \le \frac{\pi}{2}, |\delta| \le \delta^{\max} \tag{3}$$

Therefore, the problem is reduced to the optimization of the nonlinear objective function (2) with linear constraints (3). This problem can be solved using a nonlinear optimization procedure with a system of nonlinear and linear constraints, similar, for example, to the fmincon (*) MATLAB procedure

$$\text{fmincon}(@\text{fun}, \mathbf{x}0, \mathbf{A}, \mathbf{b}, \mathbf{A}\text{eq}, \mathbf{b}\text{eq}, \mathbf{l}\text{b}, \mathbf{u}\text{b}, @\text{nonlcon}) \tag{4}$$

Experiment. The workability and effectiveness of the method, algorithmic and software module of the automatic control of the vessels movement in case of an inevitable collision with the target was checked on the simulation bench [24-29], created by the authors on the basis of the Navi Trainer 5000 navigation simulator. At each step of the on-board computer of the Imitation Modeling Stand the parameters of the mutual approach of the vessel and target were evaluated, which were used to determine the optimal controls using the optimization procedure (4).

Conclusions. The issues of automatic control of the vessels movement in the event of an inevitable collision with the target in order to minimize damage are considered. It is proposed to reset the kinetic energy of the collision along the gradient. The kinetic energy gradient of the collision was determined as a function of the movement parameters - the speed of the own vessel and the difference between the courses of the vessel and the target. For the proposed method of resetting the kinetic energy of the collision along the gradient, algorithmic and software for the module of automatic control of the vessel's movement in the case of an imminent collision have been developed. The workability and efficiency of the method, algorithmic and software are checked on the Imitation Modeling Stand in the closed loop "control object - control system".

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