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Efficiency of ship movement control on the route according to the principle of deviation from the line of movement

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Abstract. The article presents the results of theoretical and marine research of modern on-board systems, including intelligent ones, aimed at optimizing the efficiency of ship operation. To reach the optimal control of the ship, the criteria for route efficiency and manoeuvring efficiency were used.

In marine research and technology, numerical methods are used, in particular, handling modified vectors to calculate the elements of the ship's motion during its drift from the impact of a place, shape, direction, and nature of action that are different in nature.

The upgraded algorithms and the formalized result are based on the theory of calculating the drift, centre of mass of ship and the compensatory regulatory impact of automation and intelligent systems. The stability, speed and accuracy of the latter is controlled by navigation aids during navigation.

Keywords: route, ship, controllability, efficiency

1. Introduction

It is proposed to control the ship according to the state by determining the magnitude, direction and coordinates of the drift velocity vector of ship according to the coordinates of the observed points and the drift angle. The control of the speed vector of the ship's path in time directed along the center plane of the ship is carried out by stages of changes in the direction of the speed vector of its movement with a constant module for the ship's center of mass to enter the route line, followed by the sliding of the speed vector along the straight sections of the route. The efficiency of movement is determined as the ratio of the length of movement to the length of the ship's path and by the drift angle. Let's consider the options for controlling driving by deviation, taking into account the start time and frequency of observations. The determination of drift velocity vectors, movement and path is carried out by a graph-analytical method using the rules of vector reversal.

It has been established that, unlike the "way point steering" driving mode, in which the control is oriented to the end point of the route segment, in order to improve the efficiency of control after the next observation, the speed vector should be directed at an angle that differs from the direction of the route segment by an angle equal to $\arcsin\left(2r / V_c\right)$, where r – the drift value, and V_c – the speed of movement, in the direction opposite to the drift. After the ship's center of mass reaches the line of the route segment $\overline{V_c}$, the direction should be changed by an angle $\arcsin\left(r / V_c\right)$ equal to the direction of the route segment in the direction opposite to the drift velocity vector. With constant drift, the direction of the vector $\overline{V_c}$ remains constant until the end of the route segment. When moving to the next section of the route, the procedure for correcting the direction of the speed vector $\overline{K_c}$ is repeated. The specified correction method of $\overline{K_c}$ is also used in case of violation of the conditions for sliding the path vector along the route segment due to the appearance of drift when changing $\overline{V_в}$.

This method is characterized by a high degree of determinism and does not require frequent observations under conditions of constant external disturbances. With "strong" external disturbances from waves and wind, the ship's seaworthiness factor begins to act, which will be further investigated as it is associated with a change in the ship's speed.

2. Statement of the problem in general

The formulation of the problem in general terms is caused by the necessity of way losses by ships on straight sections of the route, which are determined by the ratio of the length of movement L_{AB} to the length of the ship path $S_{C(AB)}$. In this case, the coefficient of geometric efficiency of the route $\eta_{AB} = L_{AB} / S_{C(AB)}$ should tend to a maximum.

The main problematic point in solving it is to keep the center of mass of the ship, usually moving at a constant speed $\overline{V_C}$ relative to the water, in section AB with the resulting speed $\overline{V_{C(P)}}$ in accordance with the conditions of vector sliding under the influence of the perturbation speed $\overline{V_в}$. The following questions remain problematic: by what principle of control, by what laws of functioning and means of control to achieve the conditions of an extremum η_{AB} .

3. Analysis of recent research and publications

An analysis of the results of previous studies that answer the questions posed indicates four ways to solve them: the course method of keeping the ship on course by performing rotational movement around the center of mass of the ship at an angle that compensates for its drift according to regulation with the help of an autopilot, course method with observation, taking into account external influences and step by step compensating the value of the lateral deviation of the ship's center of mass from the track line by means of discrete correction of the course set by the autopilot [1, 2]. The process of keeping the ship on course is formalized in a kinetic formulation relative to the center plane of the ship, and the other methods are formalized in the scalar state space and continuous time [3].

The purpose of this study was to create the principle and laws of the functioning of the autopilot, which provides the maximum η_{AB} on straight sections of the route in the presence of disturbances and restrictions.

4. Presentation of the main material of the study

The formulation of the problem of driving along the route in a kinematic form and methodology of research assumes the fulfillment of the conditions for sliding the speed vector of the ship's path $\overline{V_{C(P)}}$ along a straight segment of the route $\overline{AB}$ to overcome it at a speed of movement $\overline{V_{AB}}$. In this case, the vectors of the perturbation velocity $\overline{V_в}$ and the control vector of the velocity of the point $\overline{V_C}$ move on the center of the ship's mass. The action $\overline{V_в}$ causes its drift by the value r, which remain unknown when the ship is at the starting point A.

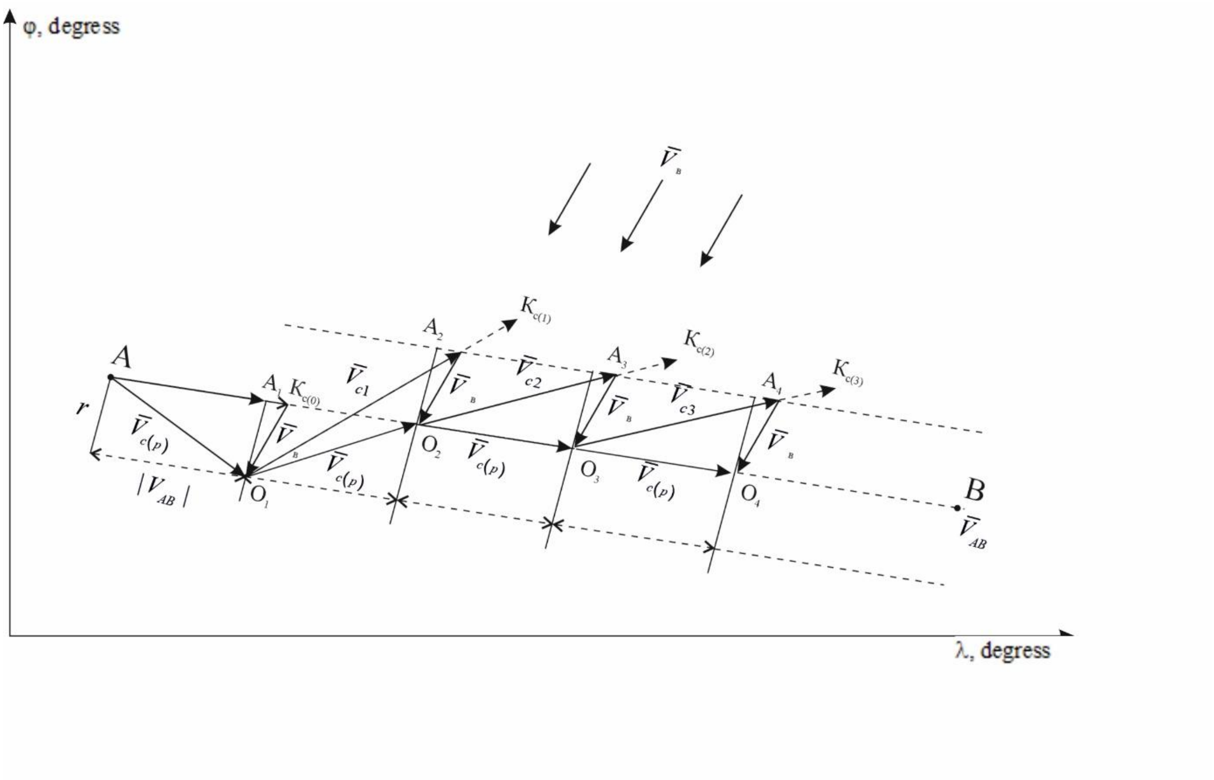

Figure 1. The nature of the rotational-translational motion of the ship's center of mass in the velocity vector state space with discrete time.

In navigation, a kinetic solution of such a problem of a prognostic nature is known, implemented in the coordinates of the ship, and even mechanisms for choosing the type of motion control vector have been proposed. However, the accuracy of the calculation results is very approximate due to the empiricism of the formulas and the coefficients included in it.

In this study, the determination of the actual total drift vector causing the deviation r of the ship's center of mass from the route line AB is determined by the state when receiving information about the position of the ship after the first dead reckoning – point O_1. This point can be determined on the line AO_1 much earlier, further transferring it to a point O_1 by time scaling. A distinctive feature of this study is the representation of the velocity vectors not only by the components $V\left(V_\varphi, V_\lambda\right)$, but also by $V\left(|V|; K_V; \varphi_{V(H)}; \lambda_{V(H)}; \varphi_{V(K)}; \lambda_{V(K)}\right)$; which significantly increases the level of informativeness of the operated data.

The module of the drift vector equal to the length of the segment KO_1 is determined by the rule of addition of the modules of the vector $\overline{V_C}$ equal to the value of the segment *AK* and $\overline{V_{C(1)}}$ equal to the length of the segment *AO*, as well as the drift angle $\angle KAO_1$ equal to α:

$$|V_в| = \sqrt{|V_C|^2 + \left|V_{C(P)}\right|^2 - 2|V_C|\left|V_{C(P)}\right|\cos\alpha}$$

The value of the module of the speed of movement of the ship $\left|V_{C(\Pi)}\right|$ equal to the value of the segment AA_1 is defined as $\left|V_{C(\Pi)}\right| = \left|V_{C(P)}\right|$, and the value of the deviation $r = \left|V_{C(P)}\right| \sin\alpha$. The efficiency of driving along the route in the considered segment will be $\eta_M = \eta_{C(M)}\eta_{C(\Pi)} = \left[1-\left(\left|V_C\right|-\left|V_{AB}\right|\right)/\left|V_{AB}\right|\right]\left[1-\left(\left|V_C\right|-\left|V_{C(\Pi)}\right|\right)/\left|V_C\right|\right]$. If $\left|V_C\right| = \left|V_{AB}\right|$, then the first factor becomes equal to 1, and the second remains less than one. The remaining components of the vectors $\overline{V_C}, \overline{V_в}, \overline{V_{C(P)}}, \overline{V_{C(\Pi)}}$ are determined by the rules of vector reversal. Usually, the solution of the problem of driving along the route associated with the exit of the center of mass of the ship from point O_1 to point O_2 and further along the route O_3, O_4, O_i, O_B is limited to verbal descriptions or reasoning that contradicts the above rules.

Therefore, the second stage of the study was the choice of additional heading angles $\overline{V_C}$ and $\overline{V_{C(P)}}$ for the ship's center of mass to reach the point O_2. The change in value $K_{C(2)}$ should allow the ship to move at a speed relative to the center plane in the direction of the bearing to the point A_2, while its relative speed of movement $V_{C(P)}$ – under the influence of the drift speed will be directed along the line O_1O_2. Since to control the ship along the course it is enough to know only the magnitude of the deviation r, then the ship's course

$$K_{C(1)} = K_{AB} \pm \arcsin\left(2r / \left|V_{C(1)}\right|\right),$$
$$K_{C(P)} = K_{AB} \pm \arcsin\left(r / \left|V_{C(1)}\right|\right)$$

After the ship's center of mass reaches the point O_2, the displacement speed $V_{C(D)}$ module will be equal to $V_{C(1)} \cos\left(K_{C(1)} - K_{AB}\right)$. At this stage, the speed $V_{C(D)}$ remains minimally unavoidable.

At the third stage of the movement from O_2 to O_3, the conditions for sliding the vector $\overline{V_{C(P)}}$ along the vector V_{AB} should be observed, i.e. provide $K_{C(P)} = K_{AB}$ at $\left|\overline{V_C}\right| = const$. To do this, reduce the value $K_{C(2)}$ to $K_{C(P)}$ to compensate for the permanent drift.

At $r \neq const$, the above procedure is repeated step by step until the condition of sliding $\overline{V_{C(P)}}$ along V_{AB} is provided.

5. Conclusions

The rotational-translational steering of the ship along the deviation is a necessary, but insufficient condition for the movement of the ship along the route, since it takes into account only the normal (perpendicular) effect of an external disturbance without taking into account its direction, as well as changes in the module of the speed of movement $\overline{V_C}$.

The influence $\overline{V_C}$ on the seaworthiness of the ship during waves, which should decrease with its increase, is also not taken into account.

The intensity of observations depends on the travel restrictions along the way and requires the establishment of such a dependence.

Controlling the direction K_C of the velocity vector of the ship's center of mass ensures its return and sliding along the route segment only with continuous consideration of the drift (deviation) value. In this case, the coefficient η_{AB} decreases in proportion to the angle of deviation K_C from K_{AB}.

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