

## **IMPROVING THE ACCURACY AND RELIABILITY OF AUTOMATIC VESSEL MOTION CONTROL SYSTEM**

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Introduction. Currently, more than 90% of all cargo in the world is transported by sea. If we also take into account the presence of a significant number of warships, we can say that the oceans have become quite “crowded”. People and their ship management decisions have caused most maritime accidents. Thus, the Dutch study "100 Sea casualties" revealed that the human factor led to 96 out of 100 accidents. According to the United Kingdom Protection and Indemnity Club, the human factor accounts for 89–96% of ship collisions, 84–88% of tanker accidents, 79% of towing ship a grounds and costs the marine industry about \$ 541 million a year. A detailed analysis of the causes of ship accidents at sea due to the human factor is given in [1]. The human factor is the weakest link in ship management. Studies of the influence of the human factor on management have been considered in the works of many authors, in particular [1 - 5]. Organizational measures taken to strengthen the training and retraining of skippers, amending the International Convention on Standards of Training, Certification, and Watch keeping for Seafarers [1] in terms of language requirements, other measures did not lead to a significant reduction in accident rates. Experts note that the only way to achieve the desired result is the development and implementation of automated decision support systems and automatic control systems.

Automated decision support systems suggest a person in the control loop and provide him with technical support, for example, in the form of monitoring the parameters of the ship's state vector and propulsion system, the formation of warning messages, control warnings, etc. In such systems, despite the technical support from automated decision support systems, the skipper makes the final decision on the control of the ship, which means , in the control chain there remains the link of the HF with partially indefinite behavior that generates a certain percentage of errors and has large delays in the processing and transmission of information [6-7].

In automatic control systems, the HF link is absent, which gives them great advantages: automatic systems are not subject to fatigue, emotions, stresses; no communication problems; information in the system is transmitted almost without delay, which is especially important when controlled inertial dimensional objects; the task can be solved optimally, which saves time and resources. In automatic systems can be achieved greater control accuracy and reliability. The accuracy of control, in the absence of a HF link, is determined only by the errors of technical devices (sensors and actuators), the scheme and accuracy of the calculations. Using mathematical methods can improve the characteristics of the input signals and increase the accuracy of control.

Relevance of research. The work [1] gives an example of a failure of the navigation equipment of the MS Royal Majesty ship. None of the crew found a failure of the equipment and did not even respond to the warning of the Portuguese fishing boats that the vessel was in danger, which ultimately led to the ship's departure from the route for 17 miles and landing aground. In automatic systems, incorrect operation or failure of navigation equipment, equipment in linear motion control channels (automation, engine, propulsion), angular movement control equipment (automation, drives, rudders) can be detected automatically by analyzing the dynamics of the control object. Most modern ships use autopilots, which are representatives of automatic systems. Similarly to autopilots, other automatic control modules can be developed that solve more complex applied problems, for example, automatic divergence with many targets [8-9], automatic wiring in narrowness, optimal maneuvering, etc. The skipper, as in the case of autopilot, only makes a decision about the involvement of the necessary module and controls the implementation of the task, and technical control of the vessel is provided automatically, according to the algorithms laid

down in the on-board controller. As follows from the foregoing, automatic control systems have huge advantages over manual control, as well as ADSS systems. Therefore, the development of such systems is an urgent scientific and technical task.

**Problem statement.** Is given a mathematical model of the movement of the control object in the form of a system of nonlinear differential equations, taking into account the effects of wind, flow and waves, a mathematical model of actuators in the form of a system of linear differential equations with a model of errors and failures, as well as a mathematical model of sensors in the form of a system of algebraic equations with model of errors and failures.

$$\frac{d\mathbf{X}}{dt} = \mathbf{F}(\mathbf{X}, \mathbf{U}) + \mathbf{W}, \quad (1)$$

$$\mathbf{X}_m = \mathbf{X} + \Delta\mathbf{X}_m + \delta\mathbf{X}_m + \nabla\mathbf{X}_m, \quad (2)$$

$$\mathbf{U} = (\mathbf{U}_l(\theta) + \nabla\mathbf{U}_l, \mathbf{U}_a(\delta) + \nabla\mathbf{U}_a). \quad (3)$$

It is required to form such controls  $\theta$  and  $\delta$  that would ensure control of the object (1) in conditions of measurement errors and failures of sensors (2) and actuators (3).

Research results. Fig. 1 shows the block diagram of the control object and the control system.

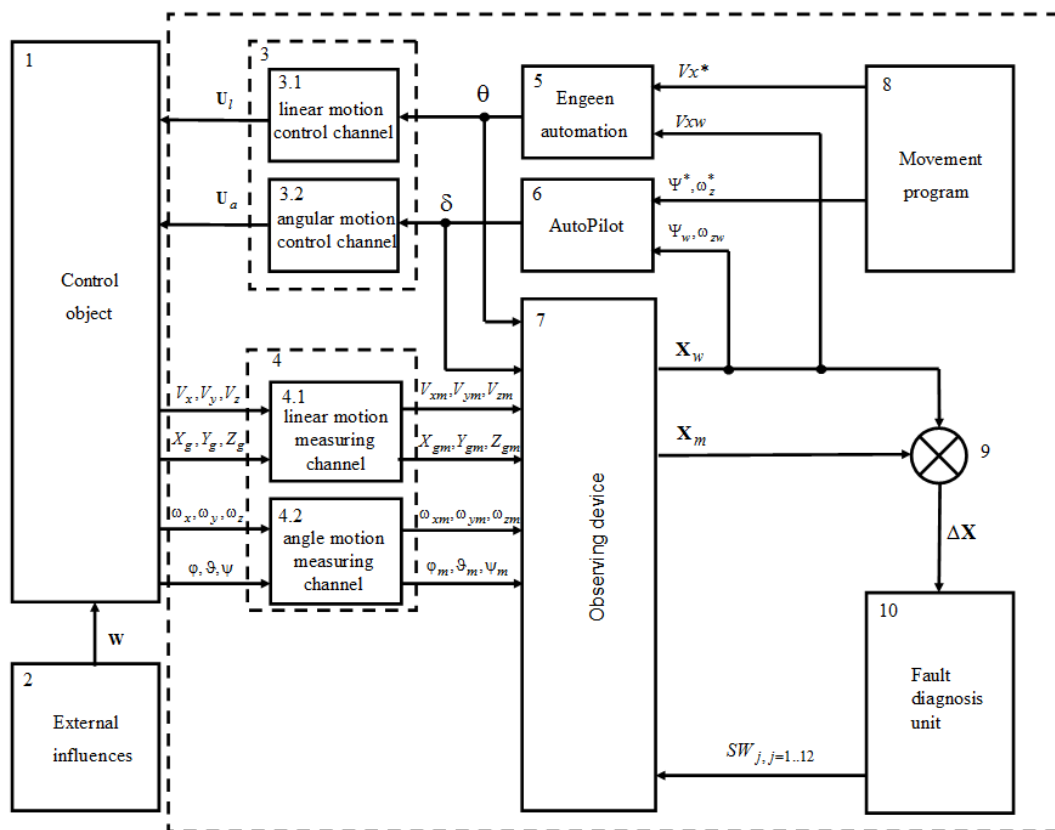


Fig. 1 – The block diagram of the control object and the control system

Observer 7 is a mathematical model of the control object and is used to estimate the state vector parameters of the control object. Due to the inaccuracy of the mathematical model and calculation errors, estimate of the state vector parameters with time will be more and more different from the state vector itself. To prevent this divergence, the observer's estimates are adjusted using the residuals between the measured parameters and their estimates.

$$\frac{d\mathbf{X}_w}{dt} = \mathbf{F}_w(\mathbf{X}_w, \mathbf{U}) + \mathbf{L}(\mathbf{X}_m - \mathbf{X}_w). \quad (4)$$

In comparator 9, the measured state vector parameters  $\mathbf{X}_m$  are compared at each step of the calculations with the corresponding estimation vector parameters  $\mathbf{X}_w$  to form the residual vector  $\Delta\mathbf{X} = \mathbf{X}_m - \mathbf{X}_w$ , which is fed to the fault diagnosis unit 10. The fault diagnosis unit 10 controls the excess of the residual vector parameters  $\Delta\mathbf{X}$  the permissible values  $\Delta\mathbf{X}^*$ . If one of the parameters  $\Delta\mathbf{X}_j$  exceeds the permissible value  $\Delta\mathbf{X}_j^*$ , the failure diagnosis unit 10 feeds to the input of the observer 7 a signal  $sw_j = 0$  to reset the  $j$ -column of the matrix  $\mathbf{L}$  in order to prevent distortion of the state vector estimates by the  $j$ -sensor. In this case, a further estimate of the state vector  $\mathbf{X}_w$  is made according to the replacement information.

Estimations of the yaw angle  $\psi_w$  and yaw rate  $\omega_{zw}$  from the output of the observer 7, as well as the required course  $K^*$  and the required yaw rate  $\omega_z^*$ , from the block of motion programs 8, are fed to the inputs of the autopilot 6, where control  $\delta$  is formed

$$\delta = k_\psi(\psi_w - K^*) + k_\omega(\omega_{zw} - \omega_z^*) + k_f \int (\psi_w - K^*) dt.$$

The speed estimation  $V_{xw}$  from the output of the observer 7, as well as the required speed  $V_x^*$  from the block of motion programs 8 are fed to the inputs of engine automation unit 5, where control  $\theta$  is formed

$$\theta = \frac{\pi V_x^*}{2 V_{\max}}$$

Verification of the operability and effectiveness of the method and algorithms for improving the accuracy and reliability of automatic vessel motion control systems in conditions of large deviations in sensors measurements during maneuvering and failures of sensors and actuators, as well as the mathematical support developed on its basis, was verified by mathematical modeling in the MATLAB environment of a control object in a closed circuit with a control system including an observer and a fault diagnosis unit.

Fig. 2 shows the results of detecting sensor failures during acceleration of the vessel and simultaneous yaw turning on 45 dg.

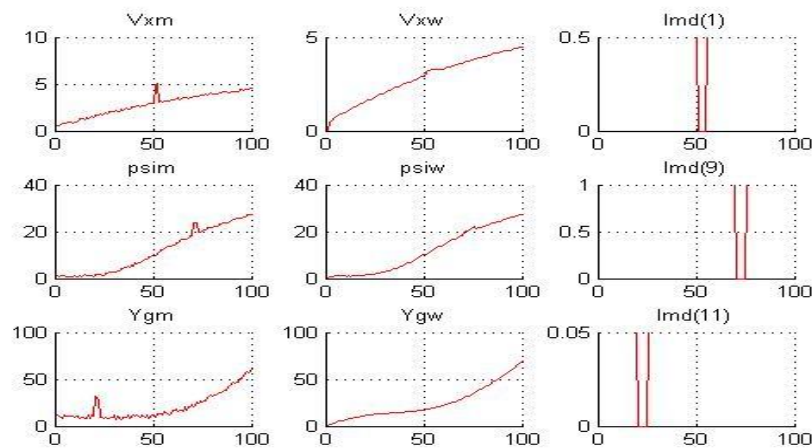


Fig. 2 – The results of detecting sensor failures

Fig. 3 shows the results of detection linear motion control channel failure, when the vessel was moving at maximum speed.

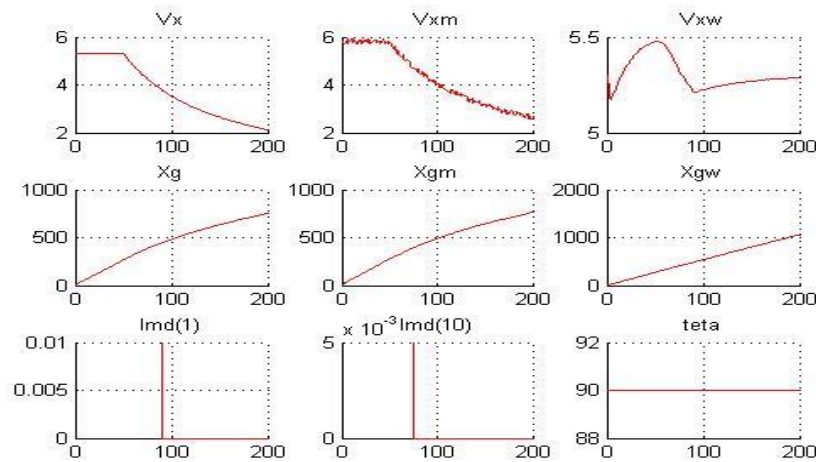


Fig. 3 – Detection linear motion control channel failure

**Conclusion.** There were proposed the method and algorithms of the vessel linear and angular motion control system, which allow to increase the accuracy and reliability of control in the conditions of significant errors of the sensors during intensive maneuvering and possible failures of the sensors and actuators. As can be seen from the results of mathematical modeling, the proposed method and algorithms, in comparison with the known solutions, make it possible to detect and parry the failures of sensors and actuators in the channels of linear and angular movement of the vessel due to the use of an observer in the control system for assessing the parameters of the state vector by measuring the parameters of motion, constant monitoring of the measured information according to the estimates of state vector parameters, forming a failure of the sensor that did not pass the control, and replacing its data with the information of another sensor working with it in pair. The failure of actuators in the control channel is detected if a simultaneous or sequential, after a short period of time, failure of the main and replacement sensors of this channel is detected.

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