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Development of technology for creating intelligent control systems for power plants and propulsion systems for marine robotic systems

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Abstract. The object of this study is to develop a power plant and an electric propulsion control system for autonomous remotely controlled vessels. The tasks of the study are as follows: to assess remotely controlled vessels usage reasonability, to define the requirements for this type of vessel navigation. In addition, the paper presents the analysis of technical diagnostics systems. The developed electric propulsion control systems for vessels should provide improved reliability and efficiency of the propulsion complex to ensure the profitability of remotely controlled vessels.

1. Introduction

A number of countries have announced programs to create remotely controlled vessels during recent few years. The creation of remotely controlled war vessels provided for an opportunity to create civil remotely controlled vessels in the field of freight services worldwide.

Rolls Royce was among the first companies who announced its intention to use drones to provide freight services [1, 2]. Mikael Makinen, Director of Rolls Royce Marine, believes that remotely controlled vessels will revolutionize the shipbuilding industry. In connection therewith, the company is actively performing research and development in the field of technologies needed to build civil remotely controlled vessels. In the Russian Federation, as well as in the countries of European Community, a program of state funding research work related to remotely controlled vessels construction was created, which also demonstrates the extreme importance of remotely controlled vessel navigation creating technologies for the development of the Russian shipbuilding industry.

2. Methods

The main risks associated with the construction of remotely controlled vessels are as follows: the complexity of the hardware and software complex necessary to manage a remotely-controlled vessel; lack of the possibility of carrying out repair work by means of the crew, which leads to increased requirements for trouble-free operation of the equipment; absence of a legal framework regulating the use of remotely-controlled vessels.

Hardware-software complex structure providing vessel movement and navigation for autonomous vessels vary from those used on inhabited vessels. To implement unmanned traffic, the vessel's current control systems must be supplemented with the elements shown in Fig. 1.

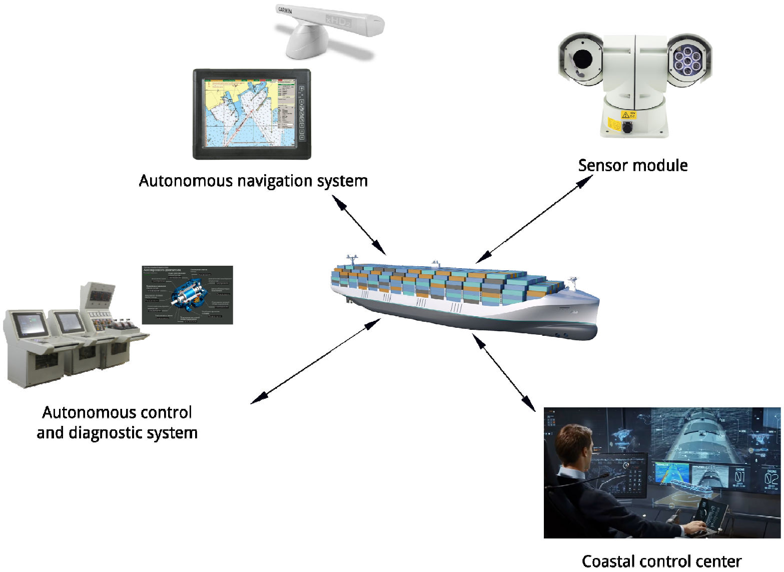

Figure 1. Complex structure providing unmanned vessel control.

The sensor module is necessary for the timely detection of objects and data transmission on the current navigation situation to the vessel's information system. The autonomous navigation system allows keeping the vessel on a pre-planned route. The autonomous control and diagnostic system sets the operating modes of the vessel's power plant. The coastal control center monitors the technical condition and movements of the vessel.

The functional structure of the subsystems providing unmanned navigation, as well as interconnections in between are shown in Fig. 2. The systems providing the traffic route construction are highlighted green. Systems that detect the current position of the vessel relatively to other objects are highlighted brown. Systems that make it possible to control the propulsion complex of the vessel are highlighted blue.

As fig.2 shows, the complex structure components providing unmanned navigation should be located in a single information space, since for accounting controlling actions on the vessel's propulsion complex it is necessary to have data on the current navigational situation, the trajectory of movement and the state of the vessel's energy system. The presence of a large number of interconnected parts, as well as the complexity of the algorithms makes the autonomous navigation complex development a technical task of high scientific value.

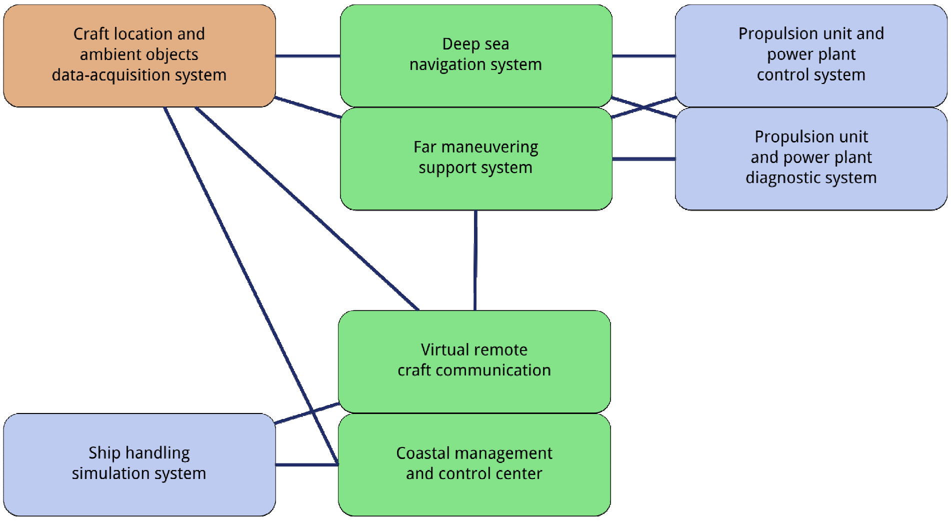

Figure 2. Functional composition of subsystems providing autonomous navigation.

3. Results and Discussion

The main goal of the transition to unmanned navigation is to reduce the costs of transport companies. Estimation of the economic effect from the creation of unmanned vessels can vary [3]. However, it was shown that it is economically inexpedient to modernize existing vessels to the level of unmanned navigation [7].

When using unmanned vessels, cost reduction is realized due to the following:

• Lack of necessity to build a life support system for the crew on board;
• Reduction ща the crew work cost;
• Fuel saving due to more efficient management of the vessel's power system.

To ensure fuel saving, it is necessary to achieve the maximum possible efficiency of the diesel generator, while maintaining the stability of the vessel's power system and the required speed of movement [5, 6].

The efficiency graph of marine diesel engines depends on the design and settings of the local control system, however, as a rule, the mechanical efficiency graph of the internal combustion engine has an extremum of approximately 85% of the nominal load, as shown in Fig. 3. [7]. When a group of diesel generators are operating on common GRU tires, the load is evenly divided between them and the shape of the graph is preserved. The task of the vessel's power system control is to select the generation and load structure so that the diesel engines work in the area of maximum efficiency. Against this requirement, there is a task of preserving the maneuverability of the vessel, as well as the need to maintain the generation reserve in case of an increase in power consumption by the vessel’s auxiliary mechanisms. In the absence of data on the trajectory of the vessel’s movement and the schedule for connecting the internal consumers of the vessel, it is impossible to keep in operation the primary engines of the generators in the area of maximum efficiency.

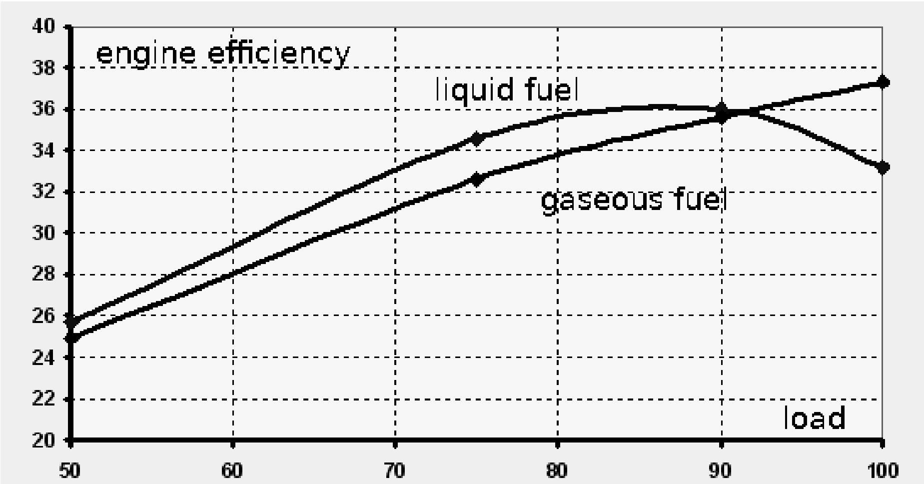

Figure 3. Dependence diagram between internal combustion engine efficiency and load level.

When creating a unified control system for an autonomous vessel, it is possible to nix the problem of the load change uncertainty. Communication technologies development level makes it possible to transmit data about:

- current level of fuel consumption;
- current parameters of the vessel's movement (speed of movement along the longitudinal and transverse axes of the vessel, vessel's angular velocity, propeller screws rotational speed and the rudder blade angle of rotation);
- accuracy requirements for the vessel following the route.

Having analyzed the communication systems, introduced to the market, it was concluded that even nowadays the power station control systems are able to adapt the current configuration of the vessel's power system to the required operating mode of the propulsion complex. One of the possible configurations of the vessel's power system control is shown in Fig. 4.

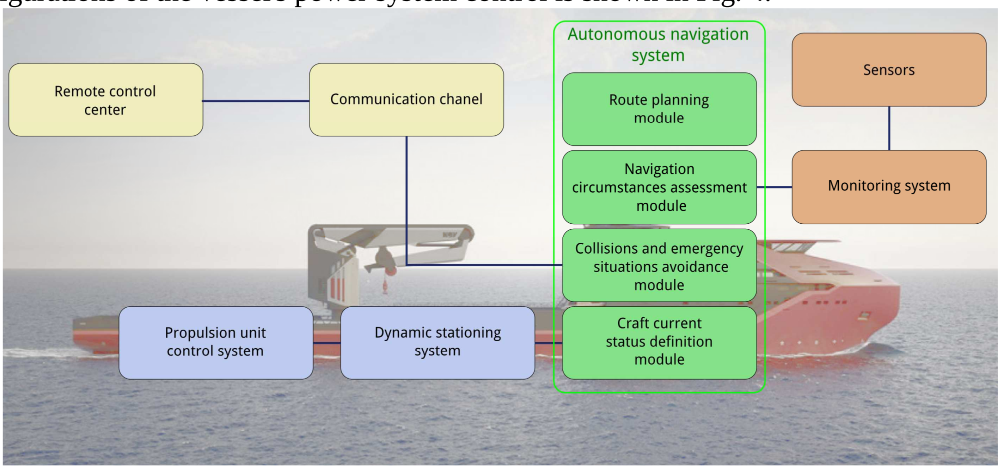

Figure 4. Elements of the shipboard control system of an autonomous vessel.

Further to the requirements on the efficiency of unmanned vessels, it is also necessary to ensure the required level of equipment reliability. For wireless vessels, operating in the high seas, it is extremely important to maintain the ability to move, as a losing movement under difficult navigational conditions can result in emergency situations, with high material costs related thereto [8, 9].

Currently, when designing ship systems, as a rule, the requirements for the availability of equipment are indicated. During the construction of unmanned vessels, this coefficient cannot be used to assess reliability due to lack of possibility to implement repair work while the vessel is moving. To this end, many technical solutions that are acceptable when developing a control system for inhabited vessels are unacceptable when creating autonomous vessels. In this regard, there is a demand that the control systems should predict the failure of mechanisms, critical for the vessel's movement, to avoid their breakdown in the high seas. In order to generalize the analysis, the vessel's electric propulsion system was divided into the following functional groups:

- Power generation;
- Power distribution;
- Screw electric drive;
- Auxiliary equipment;
- Control systems

Technical diagnosis systems analysis was carried out for each of the selected groups. Experimental prototypes of local diagnostic systems have been developed for the equipment included in each of the above-mentioned functional groups. Based on the test results of the experimental prototypes, the following conclusions were drawn:

Technical diagnostics of the state of the equipment by estimating the displacements, speed of movement and acceleration during the movement showed its efficiency for the electric power generation system. The cost of such a system is several million rubles and in the future can be reduced. This type of diagnostics allows to assess, above all, the condition of bearings, which often might be the main reason of the machinery breakdowns.

The current spectrum analysis, as of the moment, allows assessing the presence of equipment defects by indirect signs, however the use of technical diagnosis systems, based on this principle, is complicated due to the requirements for the established operating modes of the equipment. The established operating mode for shipboard equipment is the exception rather than the practice, that is why this method has a very limited scope of application;

Evaluation of the insulation resistance reduction has been used for a long time. The disadvantage of diagnosing the state of insulation resistance within a network is the fact that it does not allow to localize the insulation degradation cause.

The diagnostic methodology, based on measuring partial discharges within isolation, allows diagnosing the insulation state of a particular feeder under voltage. The main deterrent in the application of these technical diagnostic systems in practice is the extremely high cost of equipment (approximately several tens of millions of rubles).

4. Conclusion

Currently, the vessel's electric propulsion control systems are not able to provide technical diagnostics of equipment with sufficient accuracy for autonomous systems [10].

To this end, the electric propulsion systems for autonomous vessels should be developed, taking into account the limited possibilities for technical diagnostics of equipment. The development of shipboard equipment technical diagnostics systems can improve the reliability of separate units; nevertheless, the units, that are critical to the vessel's movement, should be duplicated, and the “hot” reservation requirements should be applied to the control systems.

The developed electric propulsion control systems for vessels should provide increased reliability and efficiency of the propulsion complex to ensure the remotely controlled vessels profitability. The current level of engineering science development allows developing control systems capable to reduce fuel consumption, but cannot provide the required quality of the equipment technical diagnostics.

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