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Design principles for onboard engineering diagnostics systems of unmanned maritime vessels

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Abstract. Modern information technology makes it easier to control and adequately assess the performance of marine equipment and, specifically, the elements of ship power plants, since they deliver efficient technical diagnostic services. The paper proposes the structure and principles of constructing a monitoring and diagnostic system to keep track of elements of ship power plants, enabling to solve current problems facing technical diagnostic systems.

1. Introduction

A prerequisite for the design, construction and operation of both traditional and unmanned and uncrewed vessels is to maintain the safety of the crew, vessel and cargo. Therefore, a majority of modern scientific research and development [1–2] is aimed at improving the safety of navigation. Here it is possible to highlight new sensors and devices [3–5], monitoring systems for the elements of marine systems [6–10] and individual diagnostic methods [11–16]. To a large extent, navigation safety is attributed to technical conditions and reliability of principal and auxiliary elements of ship power plants (SPP).

Highly autonomous ships must have sophisticated monitoring systems controlled by software enabling efficient analytical algorithms. There is an urgent need to control and adequately assess the performance of marine equipment and, specifically, the elements of power plants, since they specify economic and environmental functions of a ship. The challenge can be addressed by updating the existing systems for monitoring the technical state of SPP elements and their diagnostic functions. When improving the systems, it is necessary to employ the capabilities of modern measuring instruments and computer technologies in order to provide the crew and ship owner with reliable and correct information about the technical state of marine machinery and mechanisms.

2. Methods and material

Monitoring systems are mainly responsible for continuous object tracking and data collection. Depending on the results, a distinction is made between parameter monitoring systems and systems for monitoring the state of an object. In the first case, the result of monitoring is a set of measured values of parameters. In the second, it is a set of assessments of elements composing an object. In this case, the monitoring subsystem is understood not only as a set of technical means, but also a set of actions ensuring the receipt and processing of information about the object. The mandatory elements of monitoring systems are sensors selected through a set of monitored parameters (signals).

Technical diagnosis (TD) of objects is a higher-level task, which consists in assessing the performance of an object and establishing indications of potential faults or defects based on the information monitored. A distinction is made between test and functional diagnostic solutions. The first systems feature specially created test inputs. In functional diagnostic systems, the object is influenced by those inputs alone that are inextricably linked with the performance of the object. Obviously, it is not possible to generate test inputs for SPP elements during operation, so functional diagnostic systems become principal. Diagnostic systems should be tuned to detect indications of defects in technical equipment [6–7].

To establish indications of defects or violated operating parameters of equipment, the current parameters are compared with the reference, nominal characteristics [3–5]. Based on the comparison, a decision is taken as to whether it is possible to continue exploiting the equipment or there is a need for maintenance or repair activities. The technical diagnostic services involve processing experimental and calculated information, mathematical definition of parameters that determine the loading modes of units and structural elements during operation. The specified parameters are likely to encompass ambient conditions, characteristics of fuel and oil available, working process-related parameters.

A high-quality TD system is capable of reducing a number of sudden failures of engines and other elements of power plants, thus increasing the economic efficiency of fleet functioning. Indicators routinely indexed during monitoring are accumulated and generalized, which assists in preventing failures, aligning repair and maintenance programs for ship equipment.

A common attribute of marine diagnostic systems is their hierarchical structure. The primary (lower) level includes sensors and transducers that continuously collect diagnostic information about the values of monitored parameters, as well as analog and digital communication lines and power supply circuits connecting sensors and transducers with the interface module.

Next comes the data transfer level (interface module). Here, information received from sensors and transducers is collected and arranged. The module is basically located in the engine room and comprises necessary transducers, communication lines between the interlocking module and the ship's bridge or operator's workstation.

The last level is control and diagnostic, located next to the ship's bridge or on it on traditional ships. On unmanned vessels, it can be located in a special compartment, for example, in the server room. This level can be implemented either as a stand-alone device or as a specialized computer program. The interface module transmits the values via the on-board communication lines to the decision support center. The TD systems should be developed and updated in line with the best practices in the creation and operation of such systems, as well as monitoring systems [6, 7, 10].

3. Results

Based on the analysis of existing monitoring systems, a number of problems can be identified.

1. For reasons of economy, ship owners selectively use possibilities provided by monitoring systems, reducing them to control of pressures, temperatures and fuel consumption, and, as a consequence, gain insufficient information about the equipment status. Quite often, monitoring systems do not comprise a unit for analyzing measurements to be taken.

2. Most monitoring systems analyze working processes executed by machinery and mechanisms in real time, and do not provide emerging information on technical equipment.

3. In TD systems with a low degree of automation, operators have to deal with huge amounts of information arriving from sensors. Hence, there is lack of time for making a decision, the human factor is triggered, which often causes erroneous decisions that can lead to emergencies.

4. Monitoring and diagnostic systems enabling remote transmission and processing of information are immature.

To solve the above problems, the monitoring and TD system should be arranged in such a way as to provide a comprehensive control over the parameters, with the possibility of installing additional sensors for the most complete assessment, greater accuracy and reliability, with in-depth diagnostic

possibilities. It is in the integrity that information can be obtained from already existing measuring channels of control systems.

Considering the hierarchical structure of TD systems, for effective operation, it is necessary to ensure a rational choice of sensors. Then, a structural diagram of the TD system is established, based on the measurements of the principal and auxiliary SPP engines, subject to monitoring.

From the sensor unit, through the discrete data collection device, signals are sent to the operator, providing data and recommendations for further actions, to the satellite (for transmission to the ship owner for remote control), to the bridge alarm unit and alarm units (BS) located in the cabins of other workers if the vessel is unmanned. On uncrewed vessels, information is displayed on the operator's automated workstation. On the ship's bridge, the information is displayed on the monitor and recorded by the printer in a graphical form. The structure of the generated system is shown in Fig. 1.
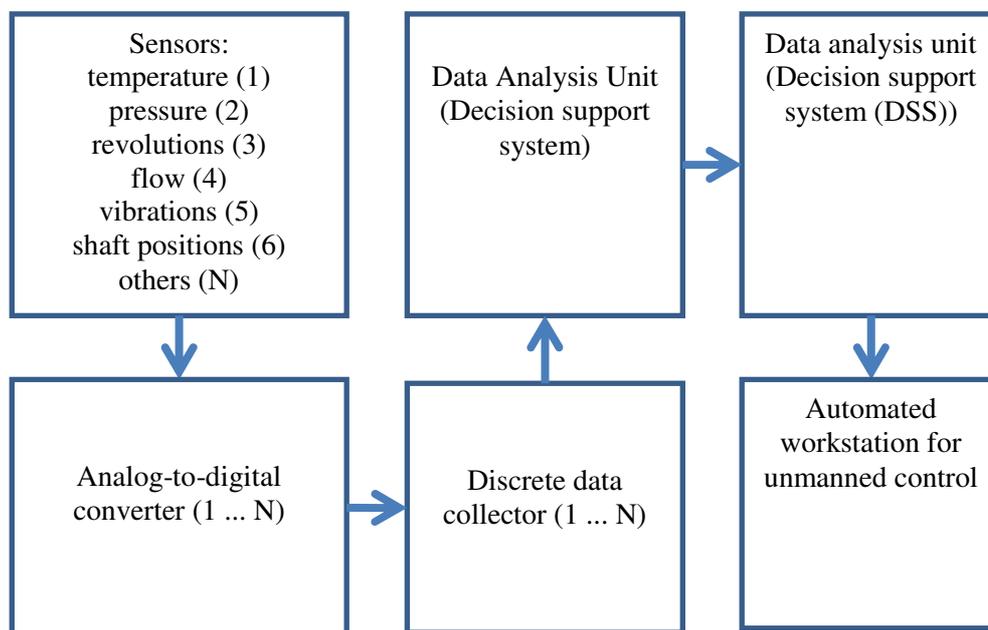

Figure 1. Structure of SPP monitoring system

The data analysis unit that performs functions of a decision support system (DSS) should ensure data collection and transmission, storage and arrangement: the possibility to sample from the stored archived data against the specified sampling attributes, process and make decisions (execution of forecasting algorithms), manage (provision of monitoring and acquisition of real-time results and forecasts for a longer period, as well as comparative analysis of early forecasts with the current situation). The information analysis and processing unit should be presented as a specialized subroutine with an interface that offers solutions to the operator and contains predictions for the current and long-term perspective of the equipment status. The functional diagram of the data analysis unit is shown in Fig. 2.

Before transferring data to the decision-making system, a unit should be provided that distributes parameters by physical characteristics for organizing samples and storing organized data as separate information. The arranged data are easier to compare and analyze, detecting deviations locally without resorting to DSS to save time. This unit is better to implement as a stand-alone device, with a monitor that the operator can also use before the data gets into the DSS and will be issued as integrated guidelines. In the DSS, Fig. 3, signals of already distributed parameters are filtered and sent for analysis, which is used by the analysis program. Today, among the methods for analyzing parameters, the most frequently used are: fast Fourier transform, regression analysis, higher order statistics. One of the promising areas is the use of neural network models [17].
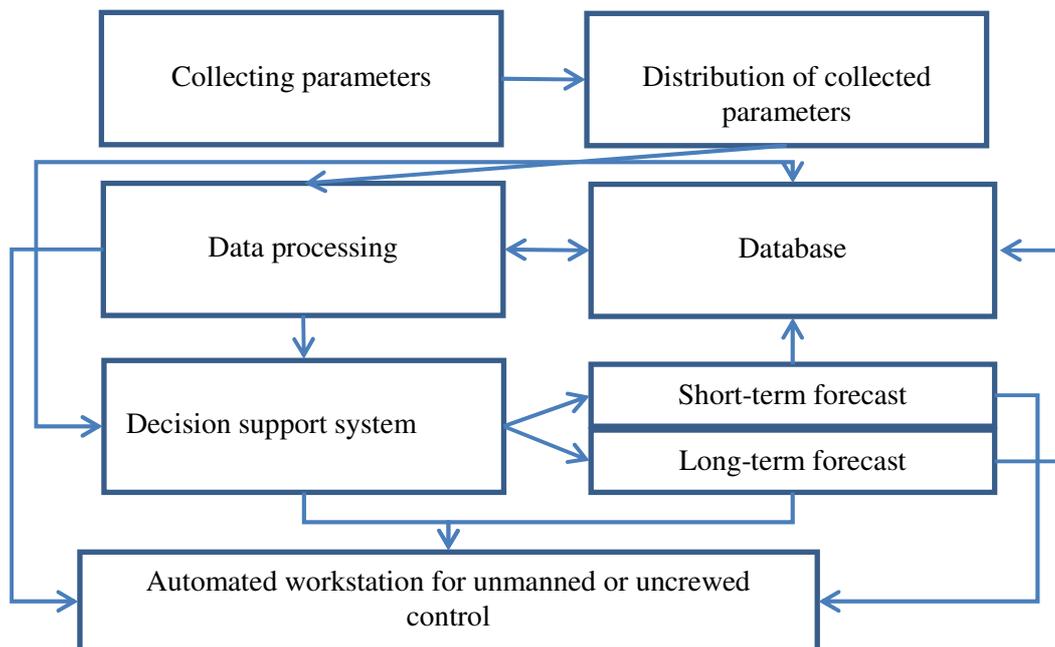
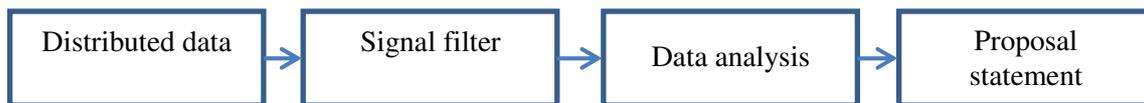**Figure 2.** Diagram of the data analysis unit (decision support system, DSS)

Figure 3. Block diagram of the decision support system (DSS)

4. Conclusion

The proposed structure and principles of constructing a monitoring and diagnostic system for the elements of a ship plant provides solutions to the existing problems faced by TD systems.

1. Implementation of a decision support system minimizes the risk of errors caused by the human factor.

2. The distribution of data (fragmenting them by physical parameters and arranging samples) at the first level of information processing enables operators to handle huge amounts of incoming information and organize it before the data enters the DSS.

3. The data analysis unit (DSS) is used to make both long-term and short-term forecasts, and to store archive data, which permits observation of marine equipment operating both in the future and in retrospect, thus showing the processes in full.

4. The selected sensors, together with the monitoring system, include an analysis unit. This produces a comprehensive representation of work processes and proposals for further equipment maintenance practices. Moreover, a full-fledged approach is demonstrated, using the analysis of both parameters and the situation at large.

5. Provided that the information generated by the data analysis unit is transmitted via satellite communication channels, the ship owner gets an opportunity to significantly enhance the economic efficiency of the fleet operation.

6. Remote monitoring and diagnostic systems to keep track of the technical status of marine machinery and mechanisms are an indispensable element of promising unmanned ships.

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