Method for synthesis of an intelligent automatic system for diagnosing combustion engine vibration of the power supply system of an unmanned vessel

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Abstract. The paper considers the implementation prospects and features of the synthesis of an intelligent automatic system for diagnosing the internal combustion engine vibration of a power supply system in terms of developing technologies for automatic or remote control of unmanned vessels. The paper addresses the issue of predicting the technical condition of a combustion engine using available diagnostic methods. The study focuses on the equipment required for monitoring and analyzing the technical condition of the engine of an unmanned vessel when operating in automatic or remotely controlled mode. An algorithm has been developed for collecting, storing and accumulating data on the condition of the engine components and units in the on-board information system of the vessel to exchange data on the condition of the engine and its components during remote monitoring and to determine fault codes. The approaches to the synthesis of an intelligent automatic system for diagnosing the combustion engine vibration are considered from a methodological point of view. Vibration diagnostics equipment used for the analysis of the technical condition of the engine is proposed. Some results of the classification of the technical condition of the engine are presented. The expediency of introducing and using hybrid intelligent systems based on artificial neural networks is exemplified by diagnostics of the MITSUBISHI S16R engine.

1. Introduction
Uninterrupted operation of a vessel’s power system (PS) largely depends on the quality of diagnostics of its units and assemblies. One of the most complex components of the PS is the internal combustion engine (ICE). Despite this, the most complete diagnostics of the combustion engine is carried out mainly within the framework of port services and during scheduled repairs, and does not provide a detailed picture of the condition of the engine during operation [1].

In this context, intelligent systems for assessing the functional condition of the ICE components are of interest since they allow continuous online monitoring by direct and indirect parameters. At the same time, a variety of information sources of various nature and purpose (sensors, detectors, etc.), as well as controllers, hinder optimal operation of the combustion engine. The key problem in the implementation of unmanned vessel (UV) technologies is an increase data flows coming from the components of dynamic systems due to PS “digitalization”, as well as their nonlinearity, multidimensionality and ambiguity [2]. All this impedes an active use of information intelligent technologies. In this context, one of the promising directions in the development of UV technical
diagnostics means is the use of artificial intelligence components: production rules, fuzzy logic, artificial neural networks, hybrid neuro-fuzzy architectures, genetic algorithms.

2. Materials and methods

With regard to the above, it seems that the introduction of intelligent neural network systems and models into the diagnostic circuit will significantly increase the efficiency of determining the current condition of the engine and predict with a sufficient degree of reliability trends in the change in time of its vibration parameters, which are identified in vibroacoustic diagnostics. The focus on the method of vibroacoustic diagnostics is due to a number of undeniable advantages, which include: 1) no need to use expensive equipment; 2) relative simplicity; 3) information value; 4) the ability to use microprocessor systems; 5) the ability to transfer data to a remote server online.

However, despite all the advantages of intelligent diagnostics methods for the PS ICE, their use for operating with significant amounts of data is mostly limited to laboratory experiments in the deferred analysis mode, and the software implementation of the neural network model is often characterized by low-speed functioning or needs special hardware.

Thus, with regard to the above, the intelligent information-measuring system for diagnosing the PS ICE condition requires further studies, which determines the topic of this paper and confirms its relevance, and theoretical and practical significance.

Such scientists as Xu, Xiaojian; Zhao, Zhuangzhuang; Xu, Xiaobin; Yang, Jianbo; Chang, Leilei; Golovko S.V., Dyachenko A.V., and Romanenko N.G. are engaged in the study of changes in the technical condition of units and systems of the PS ICE, and the peculiarities of their impact on the reliability and durability of the PS.

A number of well-known manufacturers and developers of monitoring and diagnostics systems for technical systems for various purposes are actively working on the development of a communication system between a vehicle and a remote control facility, such as Henryk Peplinski, Greczka, Grzegorz; Pilat, Tomasz; Polak, Adam; Moreva I.N., and Khromova E.V.

Lebedev B.O., Glushkov S.P., Kochergin V.I., Chris Mi, M. Abul Masrur, and David Wenzhong Gao are currently working on the development of a system for determining the fault status in the system for monitoring the technical condition of the ICE with an electronic control unit in real time.

The analysis of current developments, models and experimental data show that the systems for diagnosing the technical condition of the PS ICE based on the recording of cases of typical damages and failures compare the records of previously known damages and failures of the main components of the engine with its current technical condition. The development of such systems requires a database of failures and rather complex algorithms for pattern recognition and their classification. In addition to these obvious disadvantages, it should also be noted that the system in its classical form cannot detect defects that do not coincide with those provided in the database. Therefore, to ensure the possibility of identifying a combination of defects, artificial intelligence methods should be integrated into the technical control system, and the algorithm should be created to exchange data on the condition of the engine and its components during remote monitoring and to determine fault codes.

With regard to the above, the purpose of the paper is to consider in detail the method for synthesis of an intelligent automatic system for diagnosing the PS ICE with an electronic control unit.

From a methodological point of view, the synthesis of an intelligent automatic system for diagnosing ICE vibration typically includes the following stages:

Diagnostic features are formed based on signals of vibration velocity and acceleration;

- structural synthesis of the intellectual system: the type of neuron activation function; the number of hidden layers; determination of the number of neurons;
- parametric synthesis: training of the constructed network of established diagnostic features using a training algorithm;
- verification of the classification of the combustion engine vibration during operation [3].

Since the considered engine has an electronic control unit, it seems appropriate to use a special set of equipment for the formation of diagnostic features to allow for remote diagnostics of the vibration parameters of the ICE and store them in the memory device using DCTs (Delta Clear to Send) codes for further processing by the neural network [4–6].
3. Results

The following equipment can be used to study the PS ICE:

• vibration sensor D14.507 for measuring the quality of cylinder operation;
• electronic-mechanical sensor for recording the position of the piston and cylinder at the top dead center at the beginning of the working stroke;
• two-channel USB oscilloscope DiSco-2 for recording and quantitative processing of vibration;

Table 1 presents the key parameters of the vibration sensor and oscilloscope.

| Parameter name                                      | Parameter value                  |
|------------------------------------------------------|----------------------------------|
| **Vibration sensor D14.507**                         |                                  |
| Sensor type                                          | Piezoelectric                    |
| Conversion factor, mV * s²/M                         | 21                               |
| Electric capacity, pF (not more)                     | 1700                             |
| Output impedance, MOhm                               | 1.3                              |
| Irregularity of the amplitude-frequency characteristic,% | 10                               |
| Weight, kg                                           | 0.015                            |
| **Dual-channel USB oscilloscope DiSco-2**            |                                  |
| Measurement accuracy                                 | 1%                               |
| Noise level                                          | 3–4 mV                           |
| Input impedance                                      | 1 MOhm                           |
| Number of channels                                   | 2                                |
| Sampling frequency                                   | 100 Hz (2 channels) to 200 kHz (1 channel) |
| Memory depth:                                        |                                  |
| Reading in a buffer;                                 | 1126 or 563 samples per channel (1 or 2 channel mode) |
| Streaming read                                       | 64K readings per channel         |
| Input voltage range                                  | from ± 10 mV to + -200V          |
| Digits                                               | ADC 10 bit                       |
| Synchronization                                      | Absolute by descending/rising edge; differential by difference between readings; outer by descending/rising edge |
| Window functions                                     | Blackman-Harris, Hamming, Blackman, Hann |

To collect and store data on the vibration parameters of the ICE in the software complex, it is proposed to use the following algorithm (Fig. 1).

The data obtained by the algorithm are submitted for analysis to the input of neural networks (NN), which classify technical faults and predict the residual life of the engine. Consider the procedure of intelligent diagnostics in more detail.

Suppose that in the considered hybrid system, which consists of several NNs, there are $X_j$ inputs and $Y_n$ classes of faults. In this case, the procedure for classifying and diagnosing the technical condition of the combustion engine is implemented through the following stages:

1. Formation of training $N_0$ and test $N_T$ samples; $N = N_0 + N_T$ is the total number of examples that are stored in the database of the proposed system.

2. Clustering of the training sample. Divide the training set $K$ into $K_i$ classes (according to the number of rules), where $s = 1, 2, ..., k$. Each training subsample for $K_i$ is defined by the pair $(x_i^s, y_i^s)$, where $i = 1, 2, ... N_i$, $X_i$ is the input vector, $y_i$ is the number of classes, and $N_i$ is the number of examples in the training sample for $K_i$.

3. Choice of rules and membership functions. For each input vector of the diagnostic feature $X_i \in K_s$, determine the vector of membership functions to the rule $M_i = (m_i^1, m_i^2, ..., m_i^r)$, which is the classification of the technical condition of the engine that implements the algorithm in the form “if...
(diagnostic features), then (class of the engine technical condition), otherwise”. NN (radial-basis network) (μ) with n inputs and k classes trains on pairs $X_i, M_i, i = 1, 2, ..., N_0$. Therefore, after training and testing, this network will be able to determine the degree of membership $m_i^s$ for each input vector of the ICE diagnostic feature, which belongs to $K_s$. Thus, the membership function of the part of the rule “if ...,” is defined as the initial value $m_i^s$:

$$m_{A_s}(X_i) = m_i^s, i = 1,2, ..., N \ s = 1,2, ..., r$$

where $A_s$ corresponds to the fuzzy set of the conditional part of the s-th rule.

4. NN training. The training sample with inputs $x_{i_1}^s, x_{i_2}^s, ..., x_{i_m}^s$ and output classes of the ICE state $K_s, i = 1, 2, ..., j$ is fed to the input and output of the neural network, which is a neural network model of the part "..., then ...", (the combustion engine vibration is described by the following sets: good, acceptable, permissible, requires action, unacceptable). The test sample is used to calculate the classification error of the technical condition:

$$\varepsilon = \sum_{i=1}^{N_T} \left( Y_n - m_{A_s}(X_i) \right)^2$$

where $m_{A_s}(X_i)$ is the observed NN input.

If $\varepsilon < \Delta$, where $\Delta$ is a priori given value, the NN is trained.
The experiment employed a single-layer perceptron, Hopfield and Hamming networks, and a radial-basis network. Table 2 shows the classification of the technical condition of the MITSUBISHI S16R combustion engine.

**Table 2. Classification of the technical condition of the MITSUBISHI S16R engine**

| Neural network topology          | Training sample | Test sample |
|---------------------------------|-----------------|-------------|
|                                 | Number of errors | % | Number of errors | % |
| Single-layer perceptron         | 8               | 3.14        | 37            | 8.29        |
| Hopfield neural network         | 8               | 3.14        | 29            | 7.68        |
| Hamming neural network          | 8               | 3.14        | 21            | 4.63        |
| Hybrid intelligent system (RFB + fuzzy logic) | 8               | 3.14        | 17            | 3.67        |

The results presented in Table 2 confirm that the proposed method of intelligent automatic diagnostics of the vibration state of the PS ICE provides a minimum error in the classification of the technical condition of units and assemblies and can be used in practice.

4. **Conclusion**

Thus, the results of the study show that neural networks for diagnosing the vibration of the combustion engine with an electronic control unit, which are synthesized in the vessel’s on-board information system, improve the quality and reliability of technical data, predict the quality of ICE operation for further periods, and correct repair schedules and volumes.

**References**

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