Assessment of the technical condition of the units of mobile robotechnical complexes based on the approaches of nonlinear dynamics and artificial intelligence

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Abstract
Neural network algorithms for monitoring and diagnosing the technical condition of parts of the MRC drive axle are considered. The formalized task is a comprehensive assessment of the technical condition in the neural network basis. An engineering technique is proposed that can be applied at the stages of bench tests of critical components and assemblies.

Keywords: Technical condition; monitoring and diagnostics; learning algorithm; neural networks

In recent years, robotics is undergoing a new stage of development and covers more and more applications in both the civilian and military spheres, as well as in special working conditions. For this purpose, research is underway to develop mobile robotic systems (MRC) for various purposes. This requires the solution of new fundamental research problems related to improving the intelligence and reliability of MRC. Both the competitiveness of domestic developments in the international market and, in general, Russia's prospects in the context of scientific and technological progress depend on the success of solving these tasks.

Modern MRCs have a large number of embedded diagnostic systems. To identify irregularities in the operation of MRC, in particular, as a result of the failure of individual components or critical parts that can lead to its breakdown during movement, the diagnostic process allows you to detect malfunctions in it and in the future avoid expensive repairs. Therefore, the use of diagnostic methods and tools allows us to assess the technical condition of the main MRC components and ensure its operation is more efficient and effective.

However, given the complexity of dynamic interactions on the vehicle and in the presence of defects in critical nodes, the use of traditional methods for their diagnosis is insufficient. A number of studies have shown that the main problem in diagnosing technical equipment is the chaotic nature of the processes of wear and destruction of parts, assemblies and assemblies during operation. However, such irregular chaotic loads in the nodes of the vehicle cannot be effectively identified by traditional methods and the level of uncertainty of the technical state of the system during operation is quite high. [1-3].

A promising approach to the development of diagnostic systems for critical MRC nodes is the use of artificial intelligence, nonlinear dynamics and fractal analysis approaches. Nonlinear dynamics approaches make it possible to quantify the nature of the motion of complex systems such as MRCs and evaluate their stability at high loads. The use of artificial intelligence approaches allows us to establish a relationship between the features of the diagnostic and operational parameters of the vehicle, given the large amount of incoming information in real time, to evaluate the current technical TS of the system and optimize its operation modes.

To test the dynamic system of the MRC drive axle, a diagnostic stand for critical components and assemblies was designed. The stand consists of a PC with software, a speed indicator, a load regulator, an ADC with vibration sensors, a temperature sensor, etc. The signal sampling rate was 30 kHz, and the operating frequency band was 1 ... 15 kHz.
For signal processing, a method for processing the Vibration signal has been developed, which allows one to identify and classify pulses in the Vibration signal using approaches of nonlinear dynamics and artificial intelligence. The software structure is a series of blocks performing various tasks.

For signal analysis, the envelope spectrum method was used. The method has high sensitivity, information content and noise immunity. For signal analysis, a digital filter is used that limits the bandwidth of 1-10 kHz.

After the selection of all signal pulses, their parameters are determined. Parameters such as time maximum amplitude (A), frequency (F), entropy (E) and fractal dimension (D), the highest Lyapunov exponent (\(\lambda\)) are calculated. In addition, an attractor and wavelet scalogram are built for a more detailed analysis. The obtained characteristics of the pulses and the pulses themselves are recorded in a special database of the technical condition of the parts of the MRC unit.
Figure 3. Database Fetch Example

Information from the obtained database is used to train an artificial neural network for the task of clustering. Learning takes place without a teacher using Kohonen self-organizing cards.

Figure 4. Classification block diagram

The proposed methodology for solving the problem of diagnosing the technical condition of parts of the MRC drive axle is based on a method based on comparing the results of measurements of the Vibration signals of a physical object with the calculated parameters calculated by its mathematical model (digital twin). [6].

In fig. A typical implementation of the method is shown, where U is the vector of control actions; Ym is the vector of parameters calculated using the digital double of the rear axle of the MRC; Yg is the vector of engine output parameters obtained by measuring with sensors; ε = Yg − Ym is the error, which is the difference between the vectors Yg and Ym.

As a mathematical model, a digital twin of the MRC drive axle is used. A digital double is a combination of the use of neural network and numerical simulation using CAD, FEA, FMEA models.

Information on 5 parameters was used as diagnostic features of the input vectors: maximum amplitude (A), frequency (F), entropy (E) and fractal dimension (D), the highest Lyapunov exponent (λ) - X {x1, x2 ... x5}. As the output vectors, diagnostic features of the form D {d1, d2 ... dm} were used, where d is the technical condition expressed in the coefficients of bearings and gears.

To teach the recognition of defects in neural network modeling, five classes of states of the leading bridge were identified: C1 operable state; C2 Inoperative state; C3 Good condition; C4 Malfunctioning condition; C5 Failure.

From the results presented below it can be seen that the overall classification accuracy of the developed neural network classifier is 99.2%. Moreover, the classification accuracy of the 1st class was 89.9%, of the 2nd, 3rd, 4th, 5th classes - 100%.
Investigations were carried out both on serviceable parts and on parts with simulated defects. Defects were modeled by assembling a bridge using obviously defective parts. The frequency of rotation of the output shaft is 1200 rpm. Measurements were carried out both when the bridge was operating without load, and under load (braking torque) of 50 N·m.

When the defect reaches its maximum value, the value of information entropy, fractal dimension, and the senior Lyapunov exponent increase. This is explained by the fact that with an increase in the defect the system goes beyond its stable state, the informational entropy of the vibration signals emitted by the system increases, which is typical for chaotic systems. The attractors of the system in this case have the form of partially destroyed limit cycles with obvious chaotic perturbations. The Lyapunov exponent is changed in such a way that the stability of the system is maximum with serviceable parts. As the defect deepens, Lyapunov's senior indicator increases.

The signal entropy of the gear pairs is largely dependent on the load transmitted by the gear pair. At idle, the value of the entropy indicator is negligible. As the forces transmitted by the gearbox increase, entropy increases. This is due to increased vibration from gearings.

This feature of the work of a gear pair to identify trends in state change requires measurements at the same, and large, load. If the load is insufficient defects may not occur. If measurements that differ in time are performed at different loads of the gearbox, then all these measurements will be unsuitable for comparison with each other, for searching for changes that have occurred in the gearbox. In this regard, it is necessary to take into account the load on the node, an indicator of which is informational entropy.

**Acknowledgements**

An important property of the presented methods is a geometric generalization of the dynamic properties of systems, which facilitates understanding and perception of the features of their dynamic behavior. These geometric generalizations of the dynamic properties of systems are especially relevant at the present time - the time of development of computer technology for automated analysis and synthesis of dynamic systems.

The above methods to improve the assessment of the technical condition of critical MRC units and assemblies will allow for operational monitoring with high performance, as well as more reliable assessment of the current state of the system.

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