Automated system for diagnosing the structural failures of the unmanned vessel

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Abstract. The studies show that individual elements of a vessel component that are subjected to variable-repeated loads may be destroyed even at lower voltages than any other calculated component (unit). This problem is particularly important for the dynamically developing direction of unmanned navigation, which may be carried out with a reduced crew, in its absence – both remotely and autonomously. Conditions of cyclic variable loads in corrosive media also play an important role with a total number of operation cycles, which may reach many millions over the entire operation period. It should be noted that the statistics show that about 80% of accidents in maritime transport are caused by fatigue effects. This paper is devoted to the development of software that is able to predict fatigue failure of units and structures. The paper also describes unmanned vessel the application within an unmanned vessel, as well as the use of described mathematical algorithm in a device with the possibility of projection of augmented reality on vessel units for further prediction. The described method of predicting the strength and simplifying the service is relevant when remote security controls are required.

1. Introduction

Unmanned vessel is a technology that involves a number of aspects, in particular the way the vessel is managed, which are taken into account in the resolution of the International Maritime Organization (IMO) [1]:

• Vessel with automated processes and decision support in which crew members are on board to manage and control ship systems and functions. Some operations may be automated.
• Remotely controlled vessel with crew members on board. The ship is sailed from another place, but the crew members are on board.
• Remotely controlled vessel without crew members on board. The vessel is managed and controlled from another location. There is not a single sailor on board.
• Fully autonomous vessel: the operating system of the vessel is capable of making its own decisions and determining actions.

The implementation of unmanned vessels is based on the safety aspect. Safety is based on the following factors:

1. development of technical systems in accordance with the requirements for unmanned vessels;
2. introduction of technologies that meet environmental standards;
3. creation of an algorithm for safe operation of the vessel and its equipment;
4. requalification of ship and coastal crews.
2. Problem statement
Based on the above it can be argued that the stages of design, testing, development, service and operation require technologies that will ensure [2]:

- statistical modeling;
- semantic modeling;
- spectral analysis, etc.

Fatigue strength prediction refers to testing if durability is ultimately determined, and serves the intermediate diagnostic step. Due to a number of difficulties, in particular the cost of fatigue tests, the creation of an automated prediction system seems quite relevant.

When evaluating the strength of structural elements, the curve equation holds a critical place. It was established that voltage and durability variables are necessary to create the confidence belt zone and, based on the output algorithm, the necessary values may be determined.

3. Materials and methods
Algorithmization in the program for displaying strength characteristics (main elements of the algorithm) [3].

Let us calculate \( Y_i \), the empirical regression equation:

\[
Y_i = a + b \times (x_i - x_m).
\]

For further calculations, we need to introduce \( s^2 \), the variance of the empirical regression line:

\[
s^2 = \frac{\sum (x_i - x_m)^2}{N_yi - 2}.
\]

Next, let us define:

\[
s_a^2 = \frac{s^2}{N_yi},
\]

\[
s_b^2 = \frac{s^2}{s_a^2}.
\]

Knowing the necessary values, it is possible to calculate the variance of the mathematical expectation evaluation:

\[
S_{yi}^2 = s_a^2 + s_b^2 \times (x_i - x_m)^2,
\]

\[
S_{yi} = \sqrt{S_{yi}^2}
\]

For the final stage of the calculations it is necessary to take into account the presence of constants \( t_a, i \) and \( \alpha \). Let us introduce new variables and define the following values:

\[
N_n = 10^{Y_i - t_{ak} \times S_{yi}}
\]

\[
N_b = 10^{Y_i + t_{ak} \times S_{yi}}
\]

\[
N_a = 10^{t_{ak}}
\]

where \( N_n, N_b, N_a \) – lower, upper limit and approximation, respectively.
The software operates as follows. To enter variable values in the program dialog boxes, click “DATA ENTRY” in the program start dialog box (Figure 2). Then click “ENTER SOURCE DATA FOR CALCULATION” and enter values into the pop-up dialog boxes for cycle and stress values. After that the program will calculate the safe zone limits and the approximation zone by the built-in algorithm. Once all the data is obtained, we may start building the required graph by clicking “BUILD GRAPHS”.

![Figure 1. General structure of software operation](image)

In the popup window we see a confidence belt graph, according to which it is possible to predict the durability of certain tested objects or operating units (mechanisms). These were the sought-for curves (Figure 3). The software may predict at what point in operation the deformation is expected. For statistical data processing, an algorithm for plotting curves for the confidence belt was developed, which was used to create the software.

![Figure 2. Software dialog box for entering required variables](image)

| strain  | Upper bound | Lower bound | Approximation |
|---------|-------------|-------------|---------------|
| 26457   | 10315       | 10212       |               |
| 60193   | 27165       | 26064       |               |
| 149265  | 71134       | 70032       |               |
| 207519  | 104550      | 103450      |               |
| 276443  | 140943      | 139843      |               |
| 1989327 | 9999422     | 9889422     |               |
| 11955305| 5905305     | 5795305     |               |
| 5057501 | 26731941    | 26621941    |               |
| 9315805 | 4453805     | 4442805     |               |

| strain  | Lower bound | Approximation |
|---------|-------------|---------------|
| 26457   | 10315       | 10212       |
| 60193   | 27165       | 26064       |
| 149265  | 71134       | 70032       |
| 207519  | 104550      | 103450      |
| 276443  | 140943      | 139843      |
| 1989327 | 9999422     | 9889422     |
| 11955305| 5905305     | 5795305     |
| 5057501 | 26731941    | 26621941    |
| 9315805 | 4453805     | 4442805     |

Here are the calculated results displayed in the program dialog box. The zone being calculated includes the degree of freedom and the alpha coefficient.
This software (algorithm) must be tied to certain devices (sensors) in order to perform the current and long-term analysis. Let us consider a frame that may serve as a vacuum or electromagnetic mooring device both for a stationary and for a mobile automatic mooring device, which may be placed on board any vessel, in particular an unmanned vessel, which is an excellent solution for this type of vessels. It is necessary to place devices on the frame that will be connected to a single network for data collection. The key element of this device is a special strain-gauge transducer. There may be two options for this network of devices [5]:

- In the first case, the sensors are connected to a single microcontroller, which transmits values to the device with the software. This scheme has the only drawback – in case the microcontroller fails, the entire sensor network will cease to respond and the software will be left without data.
- The second option is to use its own microcontroller for each sensor, which will ensure that the network interacts with the software. Even if one of the devices fails, the system will continue to function partially. This option, although being reliable compared to the previous one, will definitely cost more, even if we consider that each device does not need a microcontroller with high characteristics for the purpose of data (values) processing.

Thus, having visual models of certain units or mechanisms, it is possible to obtain spectral images by “fatigue” that will be applied to the model. In addition to the current analysis, it is also possible to visualize the fatigue failure prediction and then display the deformation. This functionality is mainly possessed by modeling (design) software, such as Compass, Invertor, etc., but there are no similar analogues with a similar algorithm and the ability for direct and continuous visualization(Figure 4) [6].
4. Results and discussion

Augmented Reality (AR) is a technology that may become auxiliary, and in the future key, not only for the performance of service and operation, but also for the control of unmanned vessels. The concept of using AR and the described software is as follows [4]:

- The software environment is loaded on a microcomputer or connected to a microcontroller and assembled as a tablet. A list of values is generated when we enter and/or read the current variable(s).
- Next, the program, as previously described, calculates the required values and then draws curves.
- Besides, the software is projected onto a figure with a unit or a mechanism that is subject to prediction.
- A spectral grid and/or weak points are projected in the figure with the possibility of visualizing models for comparison and subsequent analysis of data in order to perform a service by a specialist. Thus, the specialist is able to conduct smarter operation or accurate service (Figure 5).

Such a technology may be reflected not only among marine and coastal (port) specialists, but among any representatives of engineering areas of any industry, since this section of analysis, calculation, experiment is the basis of any maintenance support. Moreover, the results that may be obtained using the proposed diagnostic and prediction system correspond to the design and testing sections of both large-scale (serial samples) and small-scale models (tests of which are carried out in laboratories, pools, sites, etc.). As noted earlier, this stage of the experiment with the use of modern intelligent technologies will allow design developers and the service providers (in case of modernization or replacement) achieving both financial and material savings. Since the diagnostics take into account the parameters of the material that is being diagnosed, it is possible to analyze the test sample from different materials without additional time costs and obtain data, on the basis of which the desired conclusions will be drawn for further activity [7].
5. Conclusion
The use of modern digital tools of operation and service is a promising direction in the implementation and use of unmanned vessels not only at the national, but also at the international level. These methods are accurate and may predict possible difficulties of service, operation, as well as possible breakdowns and indicate “weak” points of unmanned vessel elements due to various technological and technical tools [8].

The issue of creating a network consisting of a number of sensors that will be connected to a tablet, which will continuously transmit information on the body, moving parts, units, mechanisms, etc., is still relevant. One of such elements among the electronic elements of the sensors is a bending strain-gauge transducer. Programming converts resistance to a scale that will be directly proportional to certain values for prediction. It should be noted that the application of this technical tool may be reflected in the coastal infrastructure, in particular in that, which is adapted for interaction with an unmanned vessel.

There is also the issue of training specialists who will be able to use such additional equipment. In this case, the training centers for sea and coastal crews will take over the burden of advanced training. In view of the fact that the unmanned vessel as a whole is a new technology, it can be assumed that there is a need for innovations in the field of specialist training, which from additional courses of advanced training and retraining will gain the status of “specialist training” at the academic level (which will be reflected in national and international regulations) in operation, unmanned vessel service, where the use of new technologies will be reflected, possibly also using AR with specific diagnostic systems and prediction tools.

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Figure 5. Concept of using augmented reality in servicing the engine room of a vessel
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