Determination of the geometric characteristics of fatigue cracks by digital image processing method

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Abstract. The article deals with the problem of determining the rate of crack growth in the process of fatigue failure of helicopter part samples. The studies were conducted using a video recording of the experiment. Methods of digital image processing were applied to the frames of the video recording to process the data of the object destruction process. Based on the developed algorithm, computational experiments were carried out, the geometric parameters of the cracks were determined for calculating the rate of change in their sizes. The use of digital image processing methods allows significantly improve the accuracy and reduce the processing time of experimental data.

1. Introduction
In all branches of engineering, especially where accidents lead to catastrophic consequences due to the destruction of critical parts, there is a problem of timely detection and prevention of fatigue failure. Mechanisms of wear and failure of materials in various industries are well studied and presented in many scientific articles [1], there is also a large number of publications on this problem for various materials with modeling of the fracture process [2-4].

Continuous progress in the field of computer science and applied mathematics has allowed modeling to take a leading position in the design and production of modern technology. Modeling in the production of complex equipment allows to avoid a fatal error in the safety of the aircraft, or it is used after production as a maintenance tool to identify fatigue, vulnerability and degree of equipment parts destruction. To determine the main causes that affect the destruction of materials and improve the strength characteristics, it is necessary to conduct numerous experiments. Specialized programs are used for experimental data processing, their testing is carried out and optimal parameters and characteristics satisfying the specified conditions are determined [5-8].

To detect fatigue of the objects under study nondestructive testing methods are widely used [9]. The development of modern means of obtaining images, reducing their distortion, well-developed algorithms of digital image processing methods are actively used to solve this problem [10-13].

2. Objects and research methods
The paper [14] describes a technique for determining the characteristics of cracks in aircraft products. Based on this work, a method for processing the video of the crack development in the helicopter parts was developed and implemented. The object of the study is the spar of the rotor blade of the Mi-171 helicopter. The component of the helicopter was under axial tensile stress of 58.86 MPa and a bending
moment stress of 34.34 MPa. The experiment was videotaped with a GoPro HERO 4 Silver Edition action camera. The duration of the experiment is 185 hours.

At the stage of pre-processing of data from the video of crack development, the frames were selected in order to highlight cracks in the images by digital image processing methods. Image analysis was performed according to the following algorithm:

- binarization, i.e. conversion of the original image to black and white for object and background;
- determination of the crack boundaries;
- determination of the geometric parameters of the crack (length, area);
- calculation of crack growth rate.

3. Image processing results
To study crack growth rate, it is necessary to obtain information on size of a crack. Fast and accurate source image data processing plays a key role here.

The grayscale image of the crack is shown in figure 1.

![Figure 1](image)

Figure 1. $F$ – the grayscale image of the crack.

For binarization and determination of crack boundaries, a computer program has been designed using Python programming language. The binarization threshold which is used in (1) was taken as $T = 110$ (figure 2).

$$B = \begin{cases} 1 & \text{if } f[i, j] \geq T; \\ 0 & \text{otherwise}, \end{cases}$$

where $f[i, j] \in F$ is the matrix element of the source grayscale image.

![Figure 2](image)

Figure 2. $B$ – the binary image of the crack.
To determine the boundary pixels of the crack, vertical and horizontal Sobel gradient filters have been implemented [10, 11]. As a result of this stage of the algorithm, an image matrix \( V \) with boundary pixels was obtained for each image.

![Figure 3. V – the image of the boundary pixels.](image)

Quantity of pixels of perimeter \( P \) is calculated according to the formula (2), and value \( S \) as quantity of the crack area is determined by the formula (3).

\[
P = \sum_{i,j} 1 \quad \text{if} \quad v[i,j] \neq 0; \quad 0 \quad \text{otherwise},
\]

(2)

where \( v[i,j] \in V \) is the matrix element of the boundary image.

\[
S = \sum_{i,j} b[i,j] \quad \text{if} \quad b[i,j]=1; \quad 0 \quad \text{otherwise},
\]

(3)

where \( b[i,j] \in B \) is the element of the binary matrix.

The coordinates of the crack center of gravity were calculated by the formulas bellow and the center point is shown in figure 4 as a red spot with axes of inertia:

\[
\begin{align*}
\bar{x}_c &= \frac{\sum_{i,j} i \cdot b[i,j]}{S} \quad \text{if} \quad b[i,j]=1, \\
\bar{y}_c &= \frac{\sum_{i,j} j \cdot b[i,j]}{S} \quad \text{if} \quad b[i,j]=1.
\end{align*}
\]

![Figure 4. The crack centre of gravity and inertia axes.](image)

Using the coordinates of the center of gravity, the angle of inclination of the axis of inertia is calculated. The calculation results of the program for determining the crack characteristics are presented below in table 1.
Table 1. Crack geometry.

| Area S (px) | Perimeter P (px) | Center of gravity coordinates | The inertia axis angle |
|-------------|------------------|-------------------------------|-----------------------|
| 417         | 197              | $x = 240; y = 61$             | −0.827                |

The developed program determines geometric characteristics from the binary image of the crack – area, perimeter, coordinates of the center of gravity, and the angle of inclination of the axis of inertia. The calculated characteristics enable automatically monitor the behavior and the growth rate of cracks. Compared to the manual crack measurement method, the time and effort required for fatigue testing can be significantly reduced. The use of digital image processing methods improves the accuracy of calculations and effectively manage the safety and residual life of the objects under study.

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