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Improvement of image-based fatigue crack detection system

Animprovement of image-based fatigue crack detection application is proposed. The benefits of such crack detection were described.

Justification of crack growth monitoring by visual method.

The problem of establishing and ensuring the service life of aircraft is one of the main ones in its designing, manufacturing and operation. This problem involves solving a large number, as a rule, of independent tasks aimed at ensuring the bearing capacity and reliability of structural elements, units and assemblies within the fatigue life of the aircraft.

When solving such a complex of tasks the problems of structure bearing capacity prediction considering the influence of different factors acquire great importance, and such prediction should be provided both at the stage of design and manufacturing of new airplanes, and during its operation.

The current approach to aircraft design uses the principle of damage tolerance that is based on the fact that defects can exist both in new structures and in those that are in operation. On this basis, the possibility of damage and/or fracture of any element are assumed in advance and the design assumes that these fractures do not lead to the catastrophic results [1].

In this principle, while ensuring the aircraft flights safety, the appearance and propagation of fatigue cracks and their reaching the permissible length in various zones of the airframe or aircraft engine are allowed [2]. At the same time, cracks may propagate not only from cycle loadings, but also as a result of operational accidental damages or due to material defects, etc. Assuming the presence of fatigue damage within the service life, it is possible, without reducing safety, to approach the service life of aircraft structures to the maximum fatigue life of the fleet, more fully use the reserve of resistance of aircraft structures to fatigue damage without their replacement in operation [1]. Prediction of service life is possible when it is possible to evaluate the current technical condition and to predict the development of this condition in the near future in the design. On the basis of this prediction it is possible to make recommendations regarding the optimal remaining service life (before the aircraft is gone out of service or been repaired).

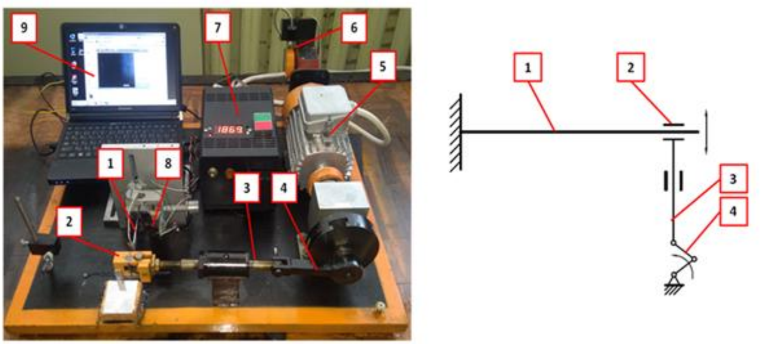
The problem of evaluation of service life characteristics and prediction of service life of aircraft structural elements comes down to timely detection of fatigue cracks.

Laboratory tests of specimens have different physical determination principles of the crack initiation and its further propagation. Usually such methods are selected on the basis of loading type, specimen material and its geometry. However, if any of the initial inputs change, the crack control method may not be as effective. Therefore, the optical method of capturing is the most universal. But it should be noted that visual detection of defects in the process of cycle testing can cause difficulties due to the resolution of the camera, focusing, etc.

In this paper, we propose a general algorithm for using a photo and video capture system for fatigue crack propagation with subsequent processing using neural networks.

Description of the test.

The components of fatigue test machine and its scheme are shown on fig.1. The Machine is specifically designed to apply bending loading to specimens without any other collateral loadings. One side of specimen is clamped while another installed in loading bogie, which apply force only in normal to specimen surface direction. The machine is powered by electrical motor. Parameter of symmetry of cyclic loading is equal to -1 which means that load cycle is symmetrical. Loading amplitude can be regulated by length of loading crank. The construction of the machine allows specimen replacement without any changes in loading, so equal loadings applied to each tested specimen.



a b

Fig. 1. General view of fatigue test machine (a) and its kinematic scheme (b): 1 - specimen; 2 – loading bogie; 3 – rod; 4 – crank; 5 – electrical motor; 6 – cycle counter; 7 – electrical control unit; 8 – web-camera; 9 – computer.

On the specimens the stress concentrator was drilled near with grip. In that place stress have highest value so cracks normally initiate there. To monitor crack initiation and propagation a camera was installed. It was specifically programmed to take pictures of specimens in predefined time intervals usually about 40 seconds which corresponds to about 1000 cycles.

The web-camera has basic resolution 1920x1080 and is designed for photo and video capturing of objects that are normally located in 50 cm in front of it. However, tested specimens were quite small so optimal distance between camera and specimen must be less than 50 mm. Such distance allows camera to capture small cracks of about 5% of specimen maximum length and large cracks that exist just before specimen fracture. A modification of the camera optical scheme was introduced, description of which is shown on fig. 2 in order to allow camera to take images of close proximity specimens.

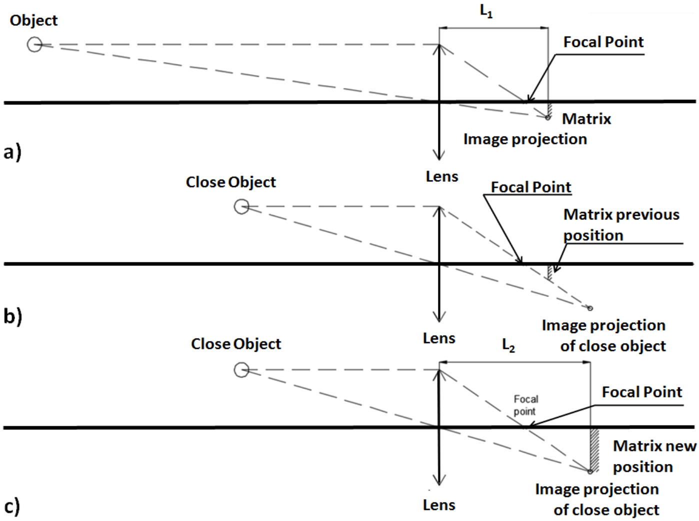


Fig.3. Optical scheme of adopting camera for close object capturing in initial position of matrix relative to lens (a); scheme with close object (b) and new position of matrix relative to lens (c).

To highlight crack on image and improve its recognition special method was developed. At first, all images from single specimen test are aligned to neglect some accidental relative camera-specimen movement. After this it was assumed that during whole test each image pixel corresponds to single point on specimen which does not change with time. Under bending loads the crack on specimen surface is tend to be opened during cycle part, when surface is under tension and closed when surface is under compression.

Closed crack is less recognizableand it can be interpreted as shorter crack. To eliminate this undesirablephenomenon average of few nearby in time images are calculated.

Next step of technique uses dynamical approach which determines how each pixel has changed relative to other pixels. This can be done, using equitation below [3]. It compare current image which is under consideration at time t_2 and image without crack at time t_1.

$$\eta_{ij} = \frac{(A_{ij} - \overline{A})(B_{ij} - \overline{B})}{\left(\frac{1}{nm}\sum_{i=0}^{n-1}\sum_{j=0}^{m-1}(A_{ij} - \overline{A})^2\right)^{1/2}\left(\frac{1}{nm}\sum_{i=0}^{n-1}\sum_{j=0}^{m-1}(B_{ij} - \overline{B})^2\right)^{1/2}} \quad (1)$$

where, i, j – coordinate on image, pixel,
n,m – size of image,
A_{ij} – intensity of pixel i,j at time moment t_1,
B_{ij} – intensity of pixel i,j at time moment t_2,
– mean value of all pixels at time t_1,
– mean value of all pixels at time t_2.

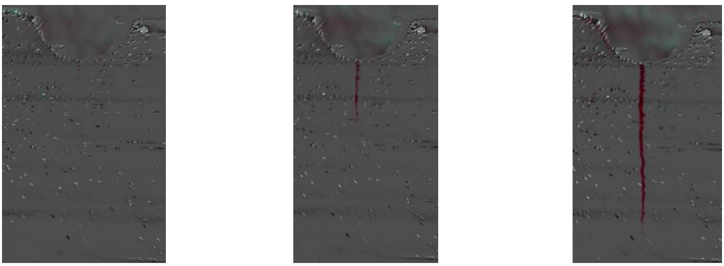
Under last step color channels of processed image with current crack and image without crack were combined to generate a new image.

Results and discussions.

Results of all steps of proceeding are represented on fig 3 and 4. Crack on processed images are highlighted by red color which help identify small crack from surface roughness blink. Moreover, computer vision program could benefit a lot from such coloring.

a) b) c)

Fig. 4. Images of fatigue crack propagation: 431489 cycles (a); 627026 cycles (b); 714090 cycles (c)



a) b) c)

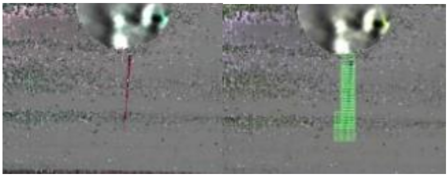
Fig. 4. Examples of image after all steps of transformation: 431489 cycles (a); 627026 cycles (b); 714090 cycles (c)

To measure length of crack on processed images the convolutional neural network together with sliding window algorithm was used. Sliding window algorithm consists in sequential analyzing of small area of single image [4]. One by one, regions of image are picked up and monitored for crack, using convolutional neural network

(CNN). Ares of image were cracked was detected are remembered and in the end of image processing they are combined, and we can see whole crack on full image.

CNN is a neural network with architecture specifically developed to deal with images. It has layers of convolution and pooling which help to reduce number of neural network weights and size of neural network in comparison to simple artificial neural network and increase efficiency in recognizing spatial patterns of image. Architecture of created CNN consist of five convolution layers with increasing number of channels, each followed by Max Pooling layer and few fully connected layers in the end. To make CCN work as desired it should be trained on training data set. From existing processed images, a lot of small parts were cutted out.This training set then where feed to CNN ADAM (adaptive momentum) training algorithm.

Results of full algorithm operation are presented on fig.5 where green squares mean that crack was detected in that area.



a b

Fig.5.Example of highlight crack (a) and detected by computer vision program region (b)

Developed program was used to collect experimental data on crack propagation during fatigue tests. It shown to be efficient and less time and work consuming than manual measurement of crack propagation curve. However, it is still requiring some human involvement on stage of image preprocess and sliding window algorithm parameter tuning.

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