Remote optical measurements of cracks in concrete structures using computer image processing

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Abstract. This report develops non-contact optical methods for measuring concrete cracks for remote diagnostics of hard-to-reach building surfaces using drones. The drone's high-resolution digital camera captures remote close-up photography of the concrete surface under high light intensity levels. The digital image of the crack converted in a data matrix, each element of which contains information about the level of reflected light from the concrete surface and the crack. Using the formulas obtained by us earlier, with the help of computer processing of the image, the morphology of the crack in real geometrical dimensions can be calculated. Using special tools computer programs, the crack’s geometrical parameters can be measured maximal accurately as possible. The proposed remote optical method for non-contact detection of cracks in concrete when photographing with a drone from a close distance allows achieving an accuracy of measuring the length and width of a crack of 5%, and its depth of 10%.

1. Introduction
Cracks in heavily loaded concrete structures are dangerous because their enlargement can lead to destruction and therefore require constant monitoring to ensure public safety. Recently, the number of publications on optical methods for detecting cracks in concrete structures has significantly increased [1-14]. The advantages of optical methods for registering problem areas are a non-contact, non-destructive method of detecting cracks and its low cost and ease of implementation, based on the latest achievements in image processing and their acquisition by mega pixels’ cameras. Previously, we proposed a method for determining the depth of a crack by processing images obtained at close range and at high light intensity, by mathematical processing of the intensity of image pixels in the OriginLab program [15]. This method allows, in the presence of a high light intensity and a close distance to the object of study, to obtain sufficiently accurate results of measuring the geometric dimensions (length, width and depth) of cracks in concrete. However, the application of this method at a considerable distance from the camera to the object of study is limited.

Huge reinforced concrete structures (hydraulic structures, multi-kilometer bridges, etc.) are of great interest for operational monitoring of the state of concrete structures, since their destruction leads to significant material losses and the detection of dangerous areas is not always possible or expensive using conventional diagnostic methods. For example, the condition of the dam near the city of Nonsan in South Korea (Figure 1) requires such constant monitoring, since the dam is under significant stress and its destruction could lead to flooding of a large area. Constant contact with water, its freezing in winter has a destructive effect on the concrete surface, causing the appearance of cracks, the size of which can increase. The use of standard contact methods for diagnosing concrete structures requires the installation of equipment on their surface, which is time-consuming and expensive. There are a significant number of the similar heavy structures that require constant monitoring of its behaviour [16].

Machine vision technologies by National Instrument have a specific tools and hardware for
computer image processing [17]. Since mathematical image processing requires a powerful computer with LabView program installed, the drone can store high-resolution images in its memory and then, after the drone returns, computer will be processing image by the method [15]. A big data can be transferred to a control computer using a connection under the newest cellular communications. In this case the image can be processed in real time.

The concrete surface reflects light diffusely [18] and has a reflection coefficient (albedo) of the order of 36-69% [19]. A feature of the photographic image of the concrete surface is that the reflected light rays from the surface elements are collected by the lens into images. When using digital cameras, a matrix of photodetectors that form image pixels. The light intensity registered by each pixel of the image corresponds to the intensity of the reflected radiation of certain areas of the real surface. In the presence of a crack in concrete, a sharp contrast of reflected light appears. Therefore, it is possible to describe the real surface of the material from their images.

Recently, the direction of surface monitoring with the help of drones (small aircraft, radio-controlled from the surface of the Earth) has been intensively developing. In particular, National Instrument (USA) [20] has created software and hardware for controlling the flight of a drone and receiving video data on a computer and capturing high-resolution images in the electronic memory of the drone. In this case, it is possible to examine the surfaces of hard-to-reach places of the monitoring object from a close distance and obtain images of the maximum surface quality of the investigated damage to the concrete structure. Then it seems possible to use the image processing technology to measure the geometric dimensions of cracks, proposed in [15].

2. Imaging processing for crack’s width, length and depth using computer tools

The digital images of the cracks were converted into a dataset, each element of which contains information about the level of reflected light from the concrete surface and cracks. In Ref. [15] is obtained formulas for width, length and depth of crack

\[ x = x_i \frac{L-f_d}{f} \]
\[ y = y_i \frac{L-f_d}{f} \]
\[ d \approx L \left( \frac{1}{\sqrt{\zeta}} - 1 \right) \]

where \( \zeta = L/f_d \), \( L \) the distance between the objective of camera and the concrete surface, \( f \) is camera focal length. These formulas have to convert to discrete form. The pixel data of the digital image was converted into real geometric parameters (width and length) by the formulas:
\[ x_i = n_i \delta (\zeta - 1), \quad y_j = n_j \delta (\zeta - 1), \]  \hspace{1cm} (1)

where \( \delta \) is camera pixel size, \( i \) and \( j \) are the number of pixels in the width and length of the image captured by the camera (Figure 2).

To obtain crack depth data, the data matrix was recalculated according to the formula:

\[ d_{i,j} \cong L \left( 1 / \sqrt{\xi_{i,j}} - 1 \right), \]  \hspace{1cm} (2)

where \( \xi_{i,j} = I^{u}_{a,i,j} / I_s \), \( I_s \) and \( I^{u}_{a,i,j} \) are experimental values of luminous intensity from undamaged concrete surface and from different depths of the crack.

Figure 2. A photo of a crack on a concrete surface with a known properties (etalon) that was captured by the drone photo equipment

Figure 2 shows a test photo of a crack on a concrete surface that was captured by the drone’s optical camera. A concrete sample with a crack was selected specifically for this experiment in order to compare the known parameters of the crack with the calculated data obtained using the proposed optical method.

Figure 3. LabVIEW program for reading an image and convert it to matrix and 3D graph.

Figure 3 shows a LabVIEW program for reading an image and converting it to a matrix and 3D
The IMAQ Create module reads data written to the computer disk. The image data is displayed on the front panel of LabView as a regular photograph using the Image module. The image data is then processed by a data matrix transform unit that displays the intensity data of each pixel in the image (Figure 4). The image data is displayed on the front panel of LabView using the special software module as a 3D graph (Figure 5). Converting the image to 3D format is useful for direct visualization of the object of study with cracks (Figure 5). It is also important to know the maximum and minimum values of the image matrix, which are determined by the tools min value and max value.

The real $x$, $y$ coordinates and the crack's depth value $d$ from the image data are calculated according to formulas (1) and (2). Results of this calculation are shown in Figures 6 and 7. Profiles of images
data (Figure 6) allow to find the crack’s geometrical size in $xy$ plane, that is, the real visible dimensions of cracks on the surface of a concrete structure. In this case, it is possible to obtain profiles of both vertical, horizontal axes, and oblique (top right distribution of Figure 6). For 36-megapixel camera with pixel size $\delta = 4.88 \mu m$ when photographing from a close distance, the resolution in measuring the width and length of the crack reaches 0.03 mm, and the measurement error is $\pm 0.1$ mm. More accurate results can be obtained by decreasing pixel sizes and increasing their number. The accuracy of measuring the length and width of a crack equals 5%. The data in Figure 6 also contains the data for the crack depth along the concrete surface. The accuracy of crack’s width and length measurements have to depend on the resolution of the camera (pixel size $\delta$).

Calculations for the depth of cracks along the surface of the sample are shown in Figure 7. Based on these data, the maximum depth and distribution of the crack depth along the cracked concrete surface can be found. The error in measuring the crack depth depends on the accuracy of measuring the distance between the camera and the concrete surface. In our case, the error is 10%.

3. Conclusion
Remoted optic measurements using drones with an installed high-resolution camera can be effectively used for monitoring the condition of concrete structures in hard-to-reach places and allows you to get high-quality images of the damaged concrete surface at close range. In this case, the use of computer image processing using the method proposed in [15] makes it possible to calculate the geometric dimensions of cracks in concrete to assess the critical state of the structure.

Using the latest, higher resolution megapixel cameras with advanced optics can improve measurement accuracy. However, increasing the size of the image leads to problems with computer processing of big data. Further development of this optical method will be associated with the development of new software and hardware.

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