

FUNDAMENTALS OF THE METHODOLOGY FOR RECOGNIZING DEFECTS IN CEMENT
CONCRETE PAVEMENTS

ОСНОВИ МЕТОДОЛОГІЇ РОЗПІЗНАВАННЯ ДЕФЕКТІВ ЦЕМЕНТОБЕТОННИХ
ПОКРИТТІВ



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Summary. The article is devoted to the results of the development of the foundations for building a methodology for recognizing defects in cement concrete coatings. An analysis of foreign sources regarding progressive methods for processing the results of photofixation of defects on critical infrastructure objects has been performed. A general algorithm for building a methodology for recognizing defects has been developed, which is based on five main steps, in particular, on collecting and summarizing data with subsequent pre-processing and filtering; improving image quality and eliminating background noise using image processing methods; using machine learning models for detection and classification; checking the correctness of the detected defect; calibrating the machine learning algorithm. It is proposed to use the harmonic mean index to

assess the efficiency of the machine learning model and as a metric for its calibration. It was determined that the practical testing of the study will be carried out within the framework of the authors' participation in the project 2023.04/0097 "Creation of a technology and a system of operational analysis and management of cement-concrete pavement condition of critical infrastructure objects based on spectral photoinformational images", financed by the National Research Fund of Ukraine.

Keywords: recognition methodology, defects in cement-concrete pavements, machine learning, recognition, calibration, average harmonic index

Introduction.

According to world experience, a progressive method for studying cracks and other defects in concrete based on image analysis is the use of machine learning models. These models have been rapidly evolving in recent times. This is confirmed by recent studies. In particular, most scientists are inclined to believe that for defect recognition in images it is advisable to use a deep learning model (Deep Learning – DL), which uses artificial neural networks to classify cracks and fractures in concrete in real time [1]. An interesting approach is to use the image clustering method based on a convolutional neural network [2-3]. The model uses a hybrid dataset of cracks in concrete, both the results of photofixation and images obtained by a thermal imager, thereby increasing the reliability of the processing results and the scale of crack detection. To detect cracks in concrete structures images, researchers are also increasingly using Deep Convolutional Neural Networks (DCNN) and Transfer Learning (TL) [4], gradient boosting algorithm for image segmentation based on Convolutional Neural Networks (CNN) [5].

However, the results of the above studies [1-5] have not yet been calibrated according to the parameters of the width and depth of the crack, the influence of lighting during the shooting, and the type of equipment, which requires the development of our own methodology.

Presenting main material.

Crack detection methods can be classified into two main groups [2]:

- methods based on machine learning (Otsu, Accelerated Algorithm, Expansion);
- methods based on image processing (CNN, DCNN, FCN, R-CNN).

Thus, a consistent organizational structure for building possible different methodologies is formed.

Summarizing foreign research, we propose the following general algorithm for constructing the methodology (Fig. 1). In this case, the first step according to the algorithm is to perform field research. The obtained images of defects must be collected and systematized into a data array. At the second stage, it is necessary to perform image recognition. In this case, noise must be removed from the image. The best method of pre-processing is segmentation of the obtained images.

Digital noise is random and randomly located (not present on the real object) changes in the brightness or color of pixels. Noise is an unwanted by-product of image capture that adds unnecessary information. It can be caused by defects in the digital matrix, too high sensitivity, or a significant change in the temperature of the matrix. Digital noise is visible in the image as a superimposed mask of pixels of random color and brightness [6]. Factors that can introduce noise into images include environmental conditions, camera sensors, etc.

Before choosing a filtering method, it is important to determine what type of noise is present:

- Gaussian noise – evenly distributed, similar to "fog".
- Salt-and-Pepper noise – random white and black dots.
- Speckle noise – multiplicative noise, often found in medical images.
- Periodic noise – manifests itself in the form of regular patterns (bands).

Deep neural networks demonstrate the best quality of image cleaning, but require significant computational resources and pre-training of models.

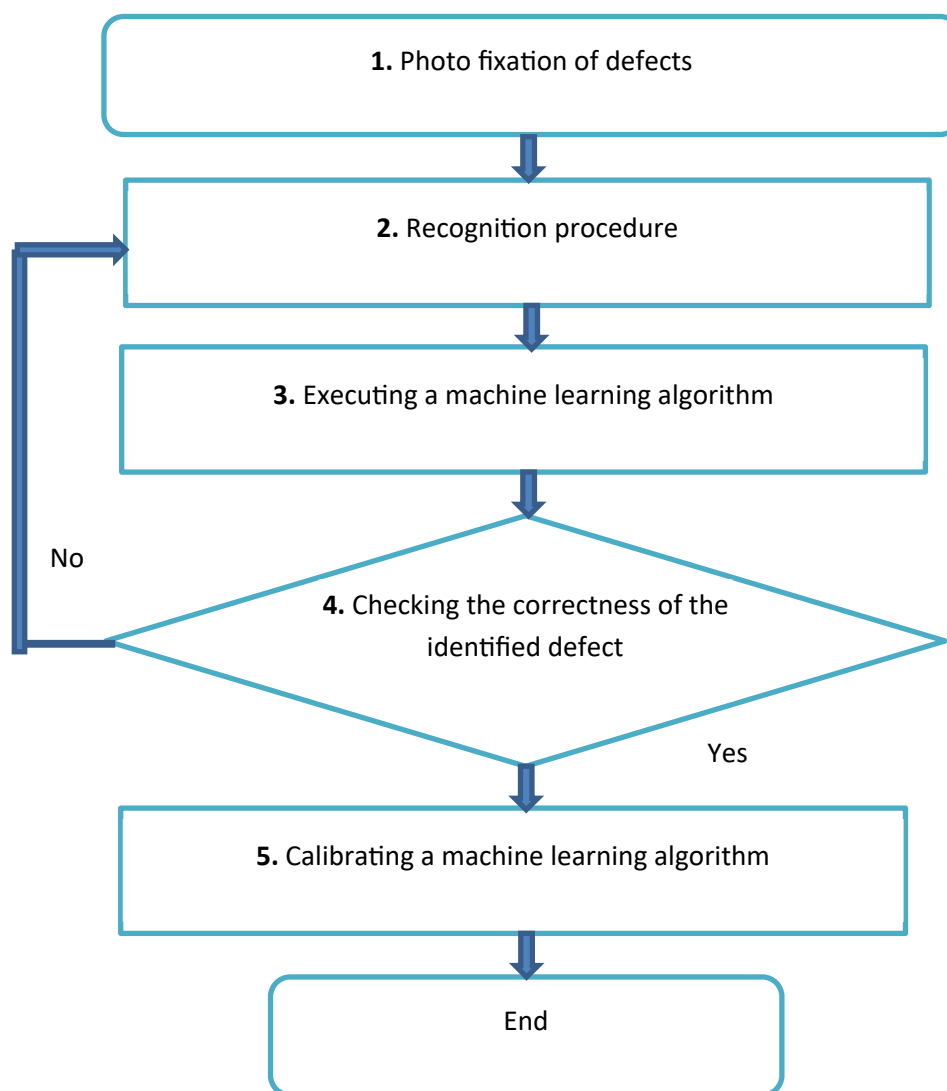


Figure 1 – General algorithm for building a defect recognition methodology

Рисунок 1 – Загальний алгоритм побудови методології розпізнавання дефектів

The third step of the algorithm involves machine learning itself. A particularly effective tool for solving such problems is the use of deep neural network technology, as already noted earlier [2-3].

Typically, image analysis by machine learning algorithms goes through the following stages:

1. Image preprocessing - improving image quality, such as increasing contrast, increasing sharpness or, conversely, blurring the image to remove noise and small insignificant details from it. All this is necessary in order to make it easier to analyze the image in the future.

2. Intermediate filtering - various filters are applied to the image in order to mark the image of the area of interest or to facilitate the work of special image analysis algorithms.

3. Detection of special features (features). This can be the selection of special points, selection of contours or some other features.

4. High-level analysis - based on the found features, specific objects will be determined in the image, and, as a rule, their coordinates. Also, segmentation or some other high-level processing may occur at this stage.

At the fourth stage, the correctness of the established defect is checked, and the accuracy indicators of the algorithm are determined. Traditionally, the average harmonic *F1* indicator [4, 5] is used to assess the performance of defect recognition, which is a key evaluation metric of the machine learning model. The *F1* indicator is based on the discrepancy matrix [7] by the number of samples with recognition scores True Positives (*TP*), False Positives (*FP*); True Negatives (*TN*); False Negatives (*FN*):

$$MF1 = \frac{TP}{FN + TP} \cdot \frac{FP}{FP + TN} \quad (1)$$

Mathematically, the *F1* indicator is defined as follows [7]:

$$f F1 = \frac{D}{R} \quad (2)$$

where *D* - the matrix (1) reliability;

R - the “recall” score.

The *F1* indicator is calculated as the harmonic mean of the reliability and recall estimates [7]:

$$F1 = \frac{2 \cdot D \cdot R}{D + R}, F1 \in 0; 100 \quad (3)$$

$$F1 = \frac{2}{\frac{1}{D} + \frac{1}{R}}, F1 \in 0; 100 \quad (4)$$

The higher the *F1* index, the better the quality of the machine learning algorithm classifier.

Since the data set on defects in cement concrete elements of infrastructure structures is quite diverse, to calculate the *F1* index in this case it will be necessary to use the “one against all” method, which will allow calculating individual indicators for each type of defect separately, with arithmetic averaging of the *F1* score as a whole according to the algorithm:

$$F1 = \frac{\sum F1_i}{n}, F1 \in 0; 100 \quad (5)$$

where *n* - the number of types of defects (classes).

The fifth stage is the calibration of the machine learning algorithm, in particular, the segmentation schemes are refined taking into account the detected errors and the *F1* score. This can be done by setting a priority for one of the scores that form the *F1* score - reliability or recall:

$$F\beta = \frac{F\beta}{F\beta + 1}, F\beta \in 0; 100, \quad (6)$$

where β - the weighting coefficient, with $\beta > 1$ preference is given to the recall assessment, with $\beta < 1$ preference is given to the reliability assessment.

Thus, building a research methodology according to the proposed algorithm should include the following components:

$$M \in A, S, MF1, F1, \beta, \quad (7)$$

where A_m - the research algorithm;

S_m - the image segmentation and noise removal model.

Thus, the developed prerequisites for building a methodology for recognizing defects in cement concrete coatings will allow in the future to build a concept and an information and analytical system.

Conclusions.

The construction of a methodology for recognizing defects in cement concrete coatings of critical infrastructure objects requires a significant revision of traditional methods and models. In particular, the modern development of information technologies allows the use of computer learning in the process of building models for recognizing defects from photo images. These models should be tested for effectiveness, for which it is advisable to use the approaches proposed in this study, in particular, for determining the harmonic index, which is a key evaluation metric of the machine learning model.

The developed approaches are planned to be practically implemented in the future within the framework of the authors' participation in the project 2023.04/0097 "Creation of a technology and a system of operational analysis and management of cement-concrete pavement condition of critical infrastructure objects based on spectral photoinformational images", financed by the National Research Fund of Ukraine.

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FUNDAMENTALS OF THE METHODOLOGY FOR RECOGNIZING DEFECTS IN CEMENT CONCRETE PAVEMENTS

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Анотація: Стаття присвячена результатам розробки підвалин до побудови методології розпізнавання дефектів цементобетонних покриттів. Виконано аналіз закордонних джерел стосовно прогресивних методів обробки результатів фотофіксації дефектів на об'єктах критичної інфраструктури. Розроблено загальний алгоритм побудови методології розпізнавання дефектів, який базується на п'яти основних кроках, зокрема, на зборі та узагальненні даних з подальшою попередньою обробкою та фільтрацією; покращенні якості зображення та усуненні фонових перешкод за допомогою методів обробки зображення; використання моделей машинного навчання для виявлення та класифікації; перевірки на коректність встановленого дефекту; калібруванні алгоритму машинного навчання. Запропоновано для оцінювання ефективності роботи моделі машинного навчання та як метрику до її калібрування використовувати показник середнього гармонійного. Визначено, що практична апробація дослідження буде виконана в рамках участі авторів в проєкті 2023.04/0097 "Creation of a technology and a system of operational analysis and management of cement-concrete pavement condition of critical infrastructure objects based on spectral photoinformational images", financed by the National Research Fund of Ukraine.

Ключові слова: методологія розпізнавання, дефекти цементобетонних покриттів, машинне навчання, розпізнавання, калібрування, показник середнього гармонійного

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