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Review of Image Based Concrete Crack Detection

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***Abstract*— Detection of cracks on concrete is very important for the renovation of concrete structures. Most of the infrastructures area unit composed of concrete. Moreover, tiny cracks that appear insignificant should grow and sooner or later cause extreme structural failure. Crack detection method is very important for quality of structure, however there are many difficulties in image-based crack detection for various reasons. This issue relates to the structural health and reliability, for that reason it ought to be resolved as early as feasible to avoid extra harm. It is fascinating to discover even the tiny cracks on concrete with the help of crack detection methods. Manual inspection lacks objectivity within the quantitative analysis. This paper discusses the various research works on the image based concrete crack detection. Accuracy, precision, recall and Fmeasure are key parameters to judge the authenticity of work.**

Keywords—Image, Concrete, Crack, Detection, Accuracy, precision, recall and Fmeasure.

I. INTRODUCTION

Manual inspection lacks objectivity within the quantitative analysis. It is quite arduous to locate cracks by means of a visual take a look at for terribly big structures. of concrete structures. Furthermore, tiny cracks that appear insignificant could grow and eventually cause severe structural failure. The firmness of structure is a very significant issue not solely within the construction part however conjointly within the conservation part. The significance of wellbeing in the facility is accumulated because of the [1] area unit in style. Therefore, development security the board framework is effectively underneath improvement recently. Crack detection is important for the inspection and evaluation during the maintenance of concrete structures. However, conventional image-based methods need extract crack features using complex image preprocessing techniques, so it can lead to challenges when concrete surface contains various types of noise due to extensively varying real-world situations such as thin cracks, rough surface, shadows, etc [2].

In statistical analysis of binary classification, the F-score or F-measure is a measure of a test's accuracy. It is calculated from the precision and recall of the test, where the precision is the number of correctly identified positive results divided by the number of all positive results, including those not identified correctly, and the recall is the number of correctly identified positive results divided by the number of all samples that should have been identified as positive.

Moreover, the enthusiasm inside the automation of the advancement the executive's framework has been amassed, because of the common foundation underneath the administration is gigantic in scale, the normal assessments zone unit required to guarantee the coherence in commission, running cost is totally significant, and in this way, the security of workers should be guaranteed[3]. By building up a productive foundation life-cycle the board framework through automation, it's feasible to make sure about the unfaltering quality of the capacity and scale back the amount of examiners, assessment, time, and support cost. In addition, we will choose the condition of the structural health objectively by exploiting and process the data [4].

Most of the infrastructures area unit composed of concrete. In these structures, one of the procedures that decides the structural health by looking at a crack on the surface of the concrete. Since the state of a solid structure area unit usually simply and directly known by reviewing the surface crack, the evaluation is ought to be done consistently to confirm sturdiness and safety inside its life-cycle [8]. Diverse research analysts have studied the automatic crack detection technique. A few researchers no inheritable the facts from structures by utilizing CCTV, optical device, and range. Amidst them, the employment of the image knowledge acquisition is used conventionally [10].

Dependability, execution, and life cycle costs square measure main problems for about all in-administration enormous structures, similar to structures, spans, atomic offices, power structures, and dams [12]. Cracks on these structures square measure a normal improvement related to differed inside and outside powers, together with the erosion of implanted support, concoction crumbling of cement, thus the machine of unfriendly stacking to the structure. The presence of cracks off and on again shows imperative trouble inside the structures [14]. In this way, to make certain the basic reliability and execution of the structure for an incredible duration, auxiliary wellbeing viewing (SHM) frameworks square measure required to forestall ruinous disappointment inside the primary stages. Structural health monitoring (SHM) method is the technique that actualizes a crack identification and methodology for building structures. The manual examination needs judgment inside the measuring. The target of this venture is to create a programmed break location framework that may investigate the solid surface and arrange the cracks with proficiency [16].

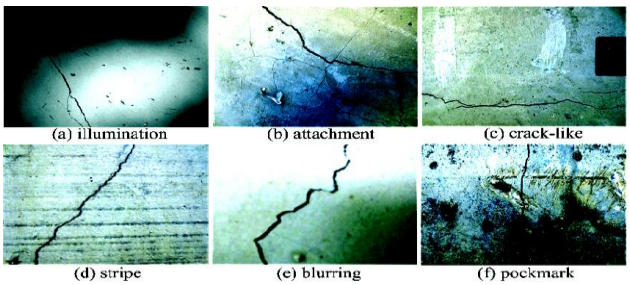

Figure 1: Concrete Crack

Fig 1 shows the different concrete cracks like illumination, stripe, blurring, pockmark, attachment and crack like. Image-based systems have several benefits for monitoring the crack propagation in different structural material. Initially, when these systems were used to measurement of cracks, more attention was paid to features of objects and repeatability [20]. Also, the use of remote sensing techniques allows the measurement of cracks without the need for access to the validated elements, and also provides stable image storage for each observation in any period. These systems are helpful for those who are involved in the design of structures or those who are responsible for maintaining the infrastructure systems when analyzing the relationship between loading and damage locations. Currently, it is aimed to utilize imaging systems for identifying cracks in images and determine certain parameters (such as length of cracks) on the one hand, and, on the other, it is desired to track how cracks are propagated over time using a set of sequential photographs. For the second purpose, generally, two approaches (or a combination of them) is used to implement systems. The first method, which has the largest share in the published works, is an approach based on image processing algorithms and developed over time using optimization algorithms. The second approach is based on a targeting method that is enriched by a combination with the comparison method. In the following sections, these two methods will be introduced with more details.

II. LITERATURE SURVEY

Shengyuan Li et al., presents an image-based crack detection method using a deep convolutional neural network (CNN). A CNN is designed through modifying AlexNet and then trained and validated using a built database with 60000 images. Through comparing validation accuracy under different base learning rates, 0.01 was chosen as the best base learning rate with the highest validation accuracy of 99.06%, and its training result is used in the following testing process. The robustness and adaptability of the trained CNN are tested on 205 images with 3120×4160 pixel resolutions which were not used for training and validation. [1]. B. Chen et al., presents the Gaussian filter is acted on the original image to obtain the smoothed image. Then the smoothed image is subtracted by the original image, the differential image is obtained. According to the OTSU algorithm, the optimal threshold on the differential image was calculated. As the characteristic cracks are a few pixels and with lower grey values, the pixels whose grey values are less than the mean value of the whole image to get the best threshold value were only calculated. Finally, remove the background noise based on the morphologic noise reduction to obtain the binary image of the crack. The experimental results show that the cracks can be discerned in complex backgrounds [2]. T. Yamaguchi et al., presents a new algorithm based on deconvolution utilizing a super high-frequency (SHF) band system. First, a distribution of reflection coefficient is inversely estimated by 1-D bridge slab model. Because concrete is found to be a lossy medium at SHF band, we consider the attenuation of signal in deconvolution. The algorithm is called "time-variant deconvolution" in this paper. After the validation by simulation, the effects of the algorithm and frequency band on damage detection accuracy are evaluated by a field the crack [3]. L. Mucolli et al., presents an unsupervised approach for crack detection in underwater concrete structures. It is based on local feature clustering using K-Medians on Haralick texture features. An additional step for outliers removal is introduced, based on a bimodal Gaussian distribution for candidate blocks. [5]. Z. Qu et al., presents method in three steps. First, the cracks are pre-extracted by the image processing model of GP. Second, the crack tip is calculated after the crack skeleton is extracted. With the endpoint as the anchor point, high speed, and high precision percolation are used to detect the cracks with small width accurately. Concurrently, the fracture unit areas are scanned for connection. The algorithm proposed in this paper can detect real concrete surface cracks accurately and effectively with strong robustness [6].

Table 1: Severe Crack

Crack type	Crack surface	Crack detection techniques	Crack Classification techniques
Large crack	Underwater dam	Particle filter method	K-means clustering, adaptive tensor voting and minimum spanning tree
Subway tunnel crack	Sub-way tunnel	Morphological operation, thresholding operation	RBF, SVM, and KNN, DNN

Table 1 explains types of crack and crack classification technique. Large cracks are detect by particle filter method. Subway tunnel crack are detect by morphological operation.J. H. Han et al., shows the solution of the issue, many methods have been proposed based on convolutional neural network but they show disconnected crack results with thin or blurred crack image. To overcome this problem, we propose a multiscale feature fusion method for crack detection. Experientially, results show that performance of our method was improved over the previous methods[7]. Y. Wang et al., presents, the contrast between the crack junction and pavement background is first enhanced by removing the large interferences and background. Then, based on the structure characteristic of crack curves, correlation structure index is

proposed to locate candidates of crack junctions. Actual junctions are extracted among the candidates with the unified ball tensor structure after the iterative tensor voting. Experimental results demonstrate that the proposed method can detect crack junctions with the correctness of 0.891 and completeness of 0.887. It can be applied to junction detection on concrete and alligator pavement with different noise and interference, and is promising to classify the crack type and quantify the severity level [8]. B. Wang et al., Presents suppress the noise disturbances, discrete cosine transformation is to extract the frequency-domain characteristics of these regions. For one new concrete image, it is first divided into many non-overlapping regions, and their sparse coefficients are fast computed on the established over-complete dictionary. Moreover then, a pooling operation is to extract the difference value between their sum coefficients on the crack templates and those on the non-crack ones, and easily yet effectively select the crack candidates via the sign bit of their difference values. [11]. R. Jain et al., shows the detection of cracks in concrete is highly recommended in early stages of construction to avoid potential hazards later. Need for automatic detection through image capturing and processing is rising. Till date only classifiers to detect cracks based on image processing have been designed. This work shows an automatic system to detect severity of cracks. Every captured image of a crack is segmented through clustering. [12]. G. YAO et al., Apparent quality of concrete is one of the important indexes of engineering quality assessment, occupying a very important position in the quality of engineering. As an important evaluation index of the apparent quality of concrete, the detection of cracks is particularly important. The traditional detection method mainly relies on the inspection personnel to carry out on-site inspection, which has low efficiency and large environmental limitations. A method of crack image recognition based on convolution neural network is proposed, which can realize the automatic recognition of concrete surface cracks, and the recognition accuracy rate is as high as 93.7% [13].

Table 2: Simple Cracks

Crack type	Surface	Crack detection techniques	Crack Classification techniques
Longitudinal crack	Bridges, pavements, concrete road and civil structure	Wavelet transform, morphological operation, KD-tree, EMD method, binarization, region growing method and fractal thresholding	SVM, random forest and adaboost
Vertical crack	Bridges, concrete road and civil structure	Particle filtering, sobel edge detection method, least square method, wavelet transform, morphological operation, KD- tree	SVM, random forest and adaboost
Diagonal crack	Concrete road, concrete pavement and civil structure	Thresholding method, segmentation, morphological operation, color feature extraction method, particle filtering, sobel edge detection method, least square method, fractal thresholding, radon transform	SVM, random forest and adaboost

Table 2 explains simple cracks. Longitudnal crack is detected by wavlet transform. Vertical crack is determined by particle filtering. Diagonal crack is determined by thresholding method. Sharma et al., presents random Forests, a combination of bagging and random subspace algorithms, has been employed and trained by inputting original RGB Training image patches along with the ground truth binary class labels to perform prediction on various concrete surface test images provided without any labels whether it belongs to a crack class or not. From the obtained experimental results, it is envisaged that the proposed method is robust enough to identify cracks in concrete structures. [16].

P. Prasanna et al., presents comprehensive analysis shows a peak STRUM classifier performance of 95% compared with 69% accuracy from a more typical image-based approach. In order to create a composite global view of a large bridge span, an image sequence from the robot is aligned computationally to create a continuous mosaic. A crack density map for the bridge mosaic provides a computational description as well as a global view of the spatial patterns of bridge deck cracking. The bridges surveyed for data collection and testing include Long-Term Bridge Performance program's (LTBP) pilot

project bridges at Haymarket, VA, USA, and Sacramento, CA, USA [17].

D. Ghosh et al., shows, the cconcrete is a heterogeneous cement-based material and when ultrasonic waves propagate through it, the waves exhibit a high degree of attenuation and scattering. This makes ultrasonic damage detection in concrete a difficult task. However, despite these difficulties, evaluation of concrete structures, using ultrasonic compressional waves, is quite popular and widespread. In this paper, we explore the feasibility of detection of near-surface damage such as radial cracks emanating from rebars, using Rayleigh waves. [18].

G. K. Choudhary et al., presents fuzzy logic and artificial neural network based models for accurate crack detection on concrete. Features are extracted from digital images of concrete surfaces using image processing which incorporates the edge detection technique. The properties of extracted features are fed into the models for detecting cracks. Two kinds of approaches have been implemented in this study: the image approach which classifies an image as a whole, and the object approach which classifies each component or object in an image into cracks and noise. [21].

Xuhang Tong et al., Presents a new method of crack image processing for concrete bridge bottom crack inspections to solve this problem. We build a machine vision system based on this method, which could detect cracks in real time. We examine the efficiency of the proposed system by evaluating it with real images of cracks and compare them with other image processing methods. In terms of efficiency and accuracy of detecting cracks, experimental results show that proposed method is superior to conventional methods in complex environments under bridges [22].

P. Wang et al., Shows many image-based detection methods have been highly proposed for their automation, objectivity and efficiency. However there are many difficulties in image-based crack detection for various reasons. In this paper, the present image-based crack detection methods are summarized and subdivided into four categories: integrated algorithm, morphological approach, percolation-based method, and practical technique [23]. Tomoyuki Yamaguchi et al., introduce an efficient and high-speed method for crack detection employing percolation-based image processing. To reduce the computation time, we consult the ideas of the sequential similarity detection algorithm and active search (SSDA). According to the concept of SSDA, the percolation process is terminated by calculating the circularity midway through the processing. Moreover, percolation processing can be skipped for the next pixel depending on the circularity of neighboring pixels [24]. Y. Fujita et al., presents two p re-processings in order to remove such noises for crack detection. First, slight variations like irregularly illuminated conditions and shading are removed from concrete images by the subtraction pre-processing with the smoothed image. Secondly, a line filter based on the Hessian matrix is used to emphasize line structures associated with cracks. Finally, thresholding processing is used to separate cracks from background [25].

III. CONCRETE CRACK DETECTION STEPS

Aapproaches use local image processing techniques to identify the crack [21]. In the local image processing techniques, it is necessary to extract some specific features of the cracks, such as the direction and the way they are connected.

Figure 2: General structure of crack detection methods

Figure 2 explains the general structure of crack detection methods like data collection, pre processing, image processing, crack detection and evaluation of parameters. These study exclusively focuses on two main crack evaluation approaches include image processing approach and targeting approach which basically have been used for assessing dimension, location and patterns of cracks. A brief comparison between these approaches and pros and cons of each process is illustrated and need of new methods to address drawbacks is also explained. New innovative methods like Wavelet, Curvelets and Contourlets transforms which know as digital image correlation techniques have addressed the image processing deficiencies in two primary damage assessment methods and are considered as new generation of image processing.

- Take data set that which consists of high-resolution images in the JPG format and corresponding binary masks to train the neural network. Some images are photos of concrete structures only, other ones have a background and extrinsic objects
- Now split each image into overlapping tiles 256X256 px. Those images have resolution 11664X8750 px and cracks are so small that after fragmentation we'll get huge imbalanced data set. Each image divided into just about 1600 samples without cracks and 150 with ones.
- However, we found an additional challenge. The most part of tiles with cracks has horizontal cracks. But cracks can be rotated at any angle. Therefore, our second step in data preprocessing is data augmentation.
- Crack detection is the semantic segmentation problem. Semantic segmentation refers to the process of linking each pixel in an image to a class label. In this case, we need to find all pixels of cracks on the photo of a concrete structure.

IV. DEEP LEARNING APPROACH

A. Deep learning algorithm

In general, the risk assessment of buildings is performed by accurately determining, quantifying, and recording the characteristics (length, width) of the cracks in concrete structures, which in turn help plan maintenance for the structures. The purpose of this study is to detect concrete cracks using deep learning and quickly determine the characteristics (crack, length) through image processing. The most common method to achieve this is to build a database of concrete crack images and to use it to segment the cracks. Segmentation refers to the conversion of low-level information (original image) into high-level information

(partitioned image), which means removing unwanted information such as noise from the images. Various algorithms for segmentation have been developed, and typical algorithms include convolution-based segmentation deep learning methods and auto encoder-based segmentation deep learning methods. The convolution-based deep learning method can convert an input image into an image that highlights the sought after characteristics by using a convolution filter, which is an image processing method. Just like applying the sobel filter, which is a filter to detect edges to create an image emphasizing edges, the method learns the appropriate filter for the problem to be solved and uses this to properly partition the segmentation target area in the input image.

B Configuration and training the deep learning method

In terms of configuring the two deep learning methods to obtain concrete crack information, at least 1,00 images of various concrete structures and concrete crack training data (data with cracks labeled) are needed for the learning process; it is very difficult to actually obtain them and manually perform crack segmentation. In addition, as the size of the architecture increases excessively in the images obtained from high resolution cameras (2960 * 1440 based on QHD), proper training becomes impossible. Since the pixels of crack images may account for less than 1% of the pixels of the entire images, the learning performance can decline significantly due to imbalanced datasets. In addition, by separating the classification and segmentation neural networks, this method can process not only fixed-sized images but also data obtained in various environments.

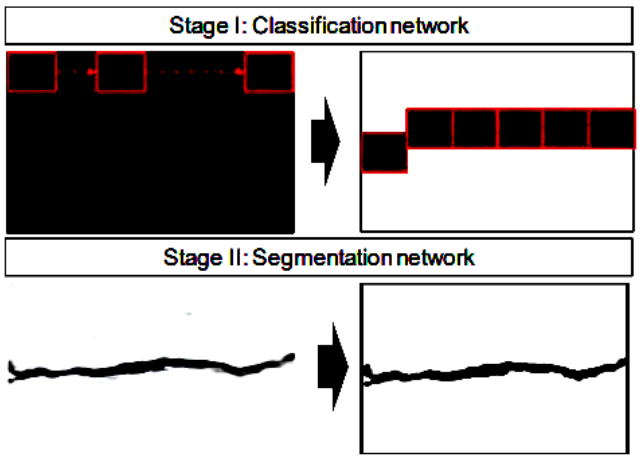

Figure 3: Image segmentation for crack detection

Figure 3 shows image segementation for crack detection. In order to detect cracks through deep learning, various training data are required for the training process to teach the neural network the different characteristics of crack and non-crack data.

C Fuzzy Logic Based DNN

A fuzzy logic management model is developed by [12] which may result in helping tin the demonstration of human information in a very targeted area of application and reasoning there with information to create helpful inferences or actions. A symbolic representation of the framework comprises of 4 sections. A fuzzifier changes over knowledge into fuzzy knowledge or Membership Function (MFs). The fuzzy rule base contains the relations between the output and input. The fuzzy illation technique joins MFs with the managerial standards to determine the fuzzy yield and in this regard the deffuzifier changes over the fuzzy numbers back to a fresh worth. There are two reasons which represent the logic frameworks. These two reasons are as follows: Fuzzy frameworks are best for uncertain or rough data and that they grant higher the cognitive procedure with measurable qualities underneath inadequate or then again uncertain information. By utilizing a fuzzy framework to adaptively change the preparation parameters of the neural system with regards to the MSE error, it is conceivable to reduce the opportunity of overshooting all through the preparation technique and encourage the system to escape a territory least.

V. CONCLUSION

In this paper, a survey on various crack detection techniques based on image processing techniques and deep learning algorithms were evaluated. The digital image processing techniques are very helpful for analyzing the defects of assorted surfaces by applying various methods like otsu method, statistical approach, median filtering, threshold method in image processing. Each method has its own merits and demerits. From this review it can be understood that some methods are fast, but lack proper accuracy, where as some other methods have high accuracy but restricted by complex computations, which leads to low speed. For real time processing, high speed and high accuracy are essential at the same time. This review shows that each method is suitable for detection of some specific defects. So it can be concluded that there is no general technique that has yet been proposed for detecting all different types of surface defects. From the survey it is understood that an increase in the depth of the deep networks will lead to better performances in terms of accuracy and recall. The deeper the networks are, the more it learns about detecting cracks although a threshold has not yet been defined.

REFERENCES

[1] Shengyuan Li, Xuefeng Zhao, "Image-Based Concrete Crack Detection Using Convolutional Neural Network and Exhaustive Search Technique", Advances in Civil Engineering, vol. 2019, Article ID 6520620, 12 pages, 2019.

[2] B. Chen, X. Zhang, R. Wang, Z. Li and W. Deng, "Detect concrete cracks based on OTSU algorithm with differential image," in The Journal of Engineering, vol. 2019, no. 23, pp. 9088-9091, 12 2019, doi: 10.1049/joe.2018.9191.

[3] T. Yamaguchi, T. Mizutani, M. Tarumi and D. Su, "Sensitive Damage Detection of Reinforced Concrete Bridge Slab by “Time-Variant Deconvolution” of SHF-Band Radar Signal," in IEEE Transactions on Geoscience and Remote Sensing, vol. 57, no. 3, pp. 1478-1488, March 2019, doi: 10.1109/TGRS.2018.2866991.

[4] K. Liu, X. Han and B. M. Chen, "Deep Learning Based Automatic Crack Detection and Segmentation for Unmanned Aerial Vehicle Inspections," 2019 IEEE International Conference on Robotics and Biomimetics (ROBIO), Dali, China, 2019, pp. 381-387, doi: 10.1109/ROBIO49542.2019.8961534.

[5] L. Mucolli, S. Krupinski, F. Maurelli, S. A. Mehdi and S. Mazhar, "Detecting cracks in underwater concrete structures: an unsupervised learning approach based on local feature clustering," OCEANS 2019 MTS/IEEE SEATTLE, Seattle, WA, USA, 2019, pp. 1-8, doi: 10.23919/OCEANS40490.2019.8962401.

[6] Z. Qu, Y. Chen, L. Liu, Y. Xie and Q. Zhou, "The Algorithm of Concrete Surface Crack Detection Based on the Genetic Programming and Percolation Model," in IEEE Access, vol. 7, pp. 57592-57603, 2019, doi: 10.1109/ACCESS.2019.2914259.

[7] J. H. Han, Y. C. Cho, H. G. Lee, H. S. Yang, W. J. Jeong and Y. S. Moon, "Crack Detection Method on Surface of Tunnel Lining," 2019 34th International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC), JeJu, Korea (South), 2019, pp. 1-3, doi: 10.1109/ITC-CSCC.2019.8793450.

[8] Y. Wang, Y. Huang and W. Huang, "Crack Junction Detection in Pavement Image Using Correlation Structure Analysis and Iterative Tensor Voting," in IEEE Access, vol. 7, pp. 138094-138109, 2019, doi: 10.1109/ACCESS.2019.2942318.

[9] H. Cho, H. Yoon and J. Jung, "Image-Based Crack Detection Using Crack Width Transform (CWT) Algorithm," in IEEE Access, vol. 6, pp. 60100-60114, 2018, doi: 10.1109/ACCESS.2018.2875889.

[10] S. Liang, X. Jianchun and Z. Xun, "An Extraction and Classification Algorithm for Concrete Cracks Based on Machine Vision," in IEEE Access, vol. 6, pp. 45051-45061, 2018, doi: 10.1109/ACCESS.2018.2856806.

[11] B. Wang, Q. Zhang and W. Zhao, "Fast concrete crack detection method via L2 sparse representation," in Electronics Letters, vol. 54, no. 12, pp. 752-754, 14 6 2018, doi: 10.1049/el.2018.0412.

[12] R. Jain and R. S. Sharma, "Predicting Severity of Cracks in Concrete using Fuzzy Logic," 2018 International Conference on Recent Innovations in Electrical, Electronics & Communication Engineering (ICRIEECE), Bhubaneswar, India, 2018, pp. 2976-2976, doi: 10.1109/ICRIEECE44171.2018.9008622.

[13] G. YAO, F. WEI, J. QIAN and Z. WU, "Crack Detection Of Concrete Surface Based On \Newline Convolutional Neural Networks," 2018 International Conference on Machine Learning and Cybernetics (ICMLC), Chengdu, 2018, pp. 246-250, doi: 10.1109/ICMLC.2018.8527035.

[14] L. Daniel Otero, M. Moyou, A. Peter and C. E. Otero, "Towards a Remote Sensing System for Railroad Bridge Inspections: A Concrete Crack Detection Component," SoutheastCon 2018, St. Petersburg, FL, 2018, pp. 1-4, doi: 10.1109/SECON.2018.8478856.

[15] A. Dixit and H. Wagatsuma, "Investigating the effectiveness of the sobel operator in the MCA-based automatic crack detection," 2018 4th International Conference on Optimization and Applications (ICOA), Mohammedia, 2018, pp. 1-6, doi: 10.1109/ICOA.2018.8370555.

[16] M. Sharma, M. K. Sharma, N. Leeprechanon, W. Anotaipaiboon and K. Chaiyasarn, "Digital image patch based randomized crack detection in concrete structures," 2017 International Conference on Computer Communication and Informatics (ICCCI), Coimbatore, 2017, pp. 1-7, doi: 10.1109/ICCCI.2017.8117742.

[17] P. Prasanna et al., "Automated Crack Detection on Concrete Bridges," in IEEE Transactions on Automation Science and Engineering, vol. 13, no. 2, pp. 591-599, April 2016, doi: 10.1109/TASE.2014.2354314.

[18] D. Ghosh, S. Beniwal and A. Ganguli, "Detection of defect in concrete slab using Rayleigh waves," 2015 IEEE International Ultrasonics Symposium (IUS), Taipei, 2015, pp. 1-4, doi: 10.1109/ULTSYM.2015.0338.

[19] P. Sekhar and R. S. Bhooshan, "Duct fan based wall climbing robot for concrete surface crack inspection," 2014 Annual IEEE India Conference (INDICON), Pune, 2014, pp. 1-6, doi: 10.1109/INDICON.2014.7030589.

[20] H. Xu, Y. Tian, S. Lin and S. Wang, "Research of image segmentation algorithm applied to concrete bridge cracks," 2013 IEEE Third International Conference on Information Science and Technology (ICIST), Yangzhou, 2013, pp. 1637-1640, doi: 10.1109/ICIST.2013.6747851.

[21] G. K. Choudhary and S. Dey, "Crack detection in concrete surfaces using image processing, fuzzy logic, and neural networks," 2012 IEEE Fifth International Conference on Advanced Computational Intelligence (ICACI), Nanjing, 2012, pp. 404-411, doi: 10.1109/ICACI.2012.6463195.

[22] Xuhang Tong, Jie Guo, Yun Ling and Zhouping Yin, "A new image-based method for concrete bridge bottom crack detection," 2011 International Conference on Image Analysis and Signal Processing, Hubei, 2011, pp. 568-571, doi: 10.1109/IASP.2011.6109108.

[23] P. Wang and H. Huang, "Comparison analysis on present image-based crack detection methods in concrete structures," 2010 3rd International Congress on Image and Signal Processing, Yantai, 2010, pp. 2530-2533, doi: 10.1109/CISP.2010.5647496.

[24] Tomoyuki Yamaguchi, Shingo Nakamura and Shuji Hashimoto, "An efficient crack detection method using percolation-based image processing," 2008 3rd IEEE Conference on Industrial Electronics and Applications, Singapore, 2008, pp. 1875-1880, doi: 10.1109/ICIEA.2008.4582845.

[25] Y. Fujita, Y. Mitani and Y. Hamamoto, "A Method for Crack Detection on a Concrete Structure," 18th International Conference on Pattern Recognition (ICPR'06), Hong Kong, 2006, pp. 901-904, doi: 10.1109/ICPR.2006.98.

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