Non Destructive Analysis of Crack Using Image Processing, Ultrasonic and IRT: A Critical Review and Analysis

P. Ramani[1], V. Subbiah Bharathi[1], and S. Sugumaran[2(✉)]

[1] SRM Institute of Science and Technology, Ramapuram, Chennai, India
ramanip@srmist.edu.in, director@srmrmp.edu.in
[2] Vishnu Institute of Technology, Bhimavaram, AP, India
sugumaran.s@vishnu.edu.in

Abstract. Crack is one of the most important surfaces damage to monuments, concrete structures, buildings, and roads. Manually examining damage is time- and labor-intensive. Crack irregularity measurements are challenging and need more expertise. Thus, develop automatic crack detection using the image processing method. This article reveals the various strategies to distinguish the crack length, width, and depth utilizing different automatic crack detection methods. In this, 53 papers describe the detection of cracks and other decay measurements. The investigation is given on the survey and dependent on the Infrared Thermography method, Ultrasonic imaging, and Image processing. The main aim of this paper is to summarize and compare the few strategies used in various Non-Destructive Techniques. Detection of the crack using Deep Learning achieves with maximum accuracy of 98%. Finally, we represent different issues that can be valuable for inquiring about to achieve further investigation on this detection.

Keywords: Degradation · Infrared thermography · Morphological operation · Ultrasonic testing · Support vector machine

1 Introduction

India is a country with a very deep and significant history and a grand heritage. Its culture and traditions are very unique, varied and celebrated the world over. Each and every district in the country has its own set of heritage structures, traditions and cultural practices. Unfortunately the cultural heritage structures and road which are exposed to the environmental changes for thousands of years undergo severe damages. The road is decayed due to frequent accessing of vehicles with a heavy load and aging. The conservation of heritage structures and road necessitates assessment of weathering decay before planning the restoration activity. The conventional method of measuring the decay involves collecting the sample from the site and conducting lab tests. Those invasive techniques are not suitable for protected heritage structures. In this context, in situ non-destructive testing methods such as Image Processing methods/machine learning are most suitable for weathering decay assessment.

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Monuments are decayed by the climate, man, rain, and other parameters. Our analysis shows how building structures like beams and concrete structures deteriorate and frequently develop cracks. Building structures are beams, concrete structures are decayed by continuous stress, and cyclic loading due to the crack is produced and cause material discontinuities. Early detection of such failures is necessary to save the building and historic cite structures. Many image processing detection methods were presented due to their ease of processing. These techniques can be divided into two groups: integrated algorithms and morphological approaches [1].

A detailed review of destructive and non-destructive techniques has been discussed in this following section. In a nutshell, it can be said that the survey is divided into four sections. Among them the first section is being dealt with the description of destructive and Non-destructive methods, the second one is about the review of various destructive and non-destructive methods and the comparison of corresponding measurement techniques, the third one is about image-based crack detection and recognition, the fourth one illustrate the accuracy based analysis, the fifth one describes the results and discussion and finally in the sixth section is about the conclusion and future work. Some of the destructive and Non-destructive methods are explained in this section.

1.1 Scanning Electron Microscopy

The images of a stone are created by continuously passing the beam of light. It provides the information of both micro and nanometric combination and also perform the analysis based on material composition [2].

1.2 Infrared Thermography

The thermal distribution of the surface is detected by the infrared method. It is used to find heat production and controls the temperature of a component. It can identify discontinuities/interfaces, defects, and voids and is difficult to detect the depth [3–5].

1.3 Ultrasonic Testing (UT)

Through the transducer, the high-frequency signal are passed to the rock. The flaws in material or parts are determined by the amount of transmitted and received energy. It is mainly used to identify the subsurface defects in the wood, plastics, and material and also difficult to inspect the thin parts. Depth is determined utilizing ultrasonic speed [6–12].

$$\text{Ultrasonic velocity} = \frac{Measuring\ distance}{Delivery\ time} \tag{1}$$

1.4 3Dimensional Terrestrial Laser Scanners

It is a new sensing technology, and it gives complex shape (like caves, historic sites). It can collect clouds of data points in few seconds and represented by horizontal and vertical view.

1.5 Image Processing

It is Non-destructive methods that processes the image automatically and obtain useful information. It uses the software to perform image processing operations on digital images to classify, extract and recognize pattern on surface [13–16]. It gives a detailed intervention compatibility and mapping of conservation.

2 Related Work

There are two techniques for surveying the decay of heritage structures and road, and they are Non-destructive and destructive methods [17]. The destructive methods are Transmitted Light Microscopy, X-ray diffraction, and Scanning Electron Microscopy [18]. In the said techniques, samples have been removed from the heritage structures and taken into the research center for examination which would eventually devastate a significant bit of monument structure. Technique of this type would not be prudent to survey the monuments.

Vibration assessment is said to be possible on a wide extent of structures such as bridges and monuments. But for these assessments the dynamic attributes of the structures like characteristic recurrence, methods of vibration, so on and so forth must be chosen delicately.

Crack has been identified and categorized by utilizing both Non-destructive and destructive techniques [1]. Some of the Non Destructive methods are Schmidt hammer that quantifies the strength of the stone, Ultrasonic imaging, Infrared Thermography and 3D Terrestrial Laser Scanner and image processing [19]. A brief description and comparison of these methods are given below and summarized in Table 1.

Antonia Moropoulou et al. (2013) proposed conservation methods for cultural heritage structures. They used various Non-destructive methods such as Digital Image Processing, Ultrasonic Testing, Infrared Thermography, and Fiber Optic Microscopy to study the decay of cultural heritage structures and the same had been validated in the lab. The ultrasonic testing technique had been used to recognize the outside and inside surface defects [20] in which a high-frequency signal had been used to identify the defects inside the stone. These techniques give flexible highlights of notable materials and furthermore, these techniques had been dealt in aiding the crack recognition and consideration of the structure. Here, the profundity of the influenced cover interior of the material is resolved [21]. An Infrared-Thermography (IRT) technique had been used to distinguish the imperfections of structural surface during night light and day light [22].

Brooks et al. (2018) developed a model to recognize the crack which has a thermal camera. The Camera had been used for distinguishing the impression of an infrared source from the exterior of the crack and the same had been used further to recognize the deformities in huge outside regions [16].

Christian Garnier et al. (2011) proposed some NDT methods and those methods were done on composite specimens to find the defect. The Graphical Visual Inspection had been used to identify the point and zone of the damaged parts. The consequences of the three strategies such as IRT, UT and Shearography are looked at and furthermore profundity is estimated using Ultrasonic Testing Method [23].

Non-destructive ultrasonic testing was used by Francesco et al. (2014) to evaluate the building materials of monuments, and elastic qualities were linked to the materials' physical and petrographic characteristics. The procedures include evaluation, observation of the weathering process, and use of refraction techniques to measure the thickness of the weather shallow area of the masonry [24]. An IRT strategy had been identified to recognize the delamination and debonding of the crack. To assess the measurement of a round and hollow specimen IRT had been utilized.

A novel technique for determining the depth of historic structures was developed by Pascale et al. (2015). The obtained result explained about the hardness of the damage and the maximum depth that had been obtained was 20mm. Time of Flight was measured on the sculpture zone [25]. The fused IRT and UV approach, which analyses and evaluates the condition of timber, was proposed by Kandemir et al. in 2007. The aforementioned procedure improved the alloy to make it suitable for long-term conservation programs. [12].

Rafael Fort et al. (2013) used a variety of techniques to evaluate two unique heritage structures. On the granite stone, a Schmidt hammer rebound experiment was conducted.

Table 1. Comparison of various methods and measurement

Methods	Parameter	Advantages	Disadvantages
Ultrasonic testing	Interfaces, voids, pores and fusion	Precise measurement	Control time is slow and the decision of explicit pores of every example
IRT	Surface temperature, discontinuities/interfaces, voids and debonding [30]	Control time is fast and a decent assessment of deformity measurement	Defect depth is not directly determined
Schmidt hammer rebound	Strength	A quick time of control constantly embraced every geometric kind	Slightly destructive technique
3D Terrestrial laser scanner	Voids, walls, columns and pillars in building structures, shapes and micro pores	Distance measured at every pointing direction, millimeter or sub-millimeter accuracies can be achieved	Care should be taken during the bundle adjustment
Digital Image Processing methods	Defective regions, shape, length and width of defective area	Fast analysis. Used in medical applications, video processing, robot vision	Require knowledge in software and the initial cost can be high depending upon the system used

The correlation coefficient between open porosity and water immersion were estimated as 0.99 [26].

Reis, H.C. et al. (2021) proposed the detection and classification of crack using deep learning techniques. The performance of proposed method is compared using SVM, Alexnet and decision tree. The accuracy of the proposed method that is ReCRNet provides better performance than existing methods [20]. Maria Auxiliadora et al. (2011) proposed a new method to detect the efflorescence of monuments in which the damage of a stone surface is classified and quantified. They also quantified the different weathering state of materials by efflorescence [27, 28].

Ramani P. et al. (2020) developed an image-processing method for the automatic detection of and classification of the crack decay. Crack is detected using combined canny with BHT and extracted the DWT features from the fused method. Crack length, location, width, orientation are measured using proposed method. Performance are evaluated in terms of accuracy, precision and selectivity, etc. This method improves the performance than existing methods [29].

3 Method

The image-based crack detection is described in Sect. 1. Accuracy-based detection is discussed in the second part.

3.1 Image Based Crack Detection

There are few challenges in image detection particularly due to poor lighting conditions and shading in the acquired images. The image based crack detection algorithms are simple and automatic in nature. Many algorithms had been developed for crack detection and they are canny edge detection, Bottom Hot Transform, Morphological approach and so on and so forth.

To distinguish exploration challenges and to accomplish better performances a point-by-point review must be done. It has been noted down that many researchers have been proposing many techniques that could identify cracks in decay monuments and road. Their various exploration works has been surveyed and analyzed. The association of the survey at first starts up with the image processing-based crack detection and other decay detection with non-destructive methods.

Crack and Other Decay Detection Using an Image Processing. This area defines the fundamental building structure of crack and other decay analysis and detection.

The schematic diagram of image processing for crack and other decay detection is shown in Fig. 1. The image of intrinsic sites from the high-resolution camera has been collected at first. Then, these images are preprocessed to remove the noise and resizing has been made. An improvement technique has increased the quality of the image, and crack and efflorescence decay features are extracted. Thus, the cracks are separated and geometrical characteristics of crack such as width, length, major axis, minor axis, perimeter and direction of propagation are measured. Thus in the above

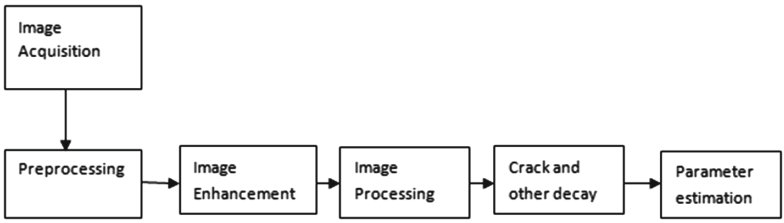

Fig. 1. Block Diagram of Crack analysis

schematic diagram the image processing approach for the detection of other decay and crack in monuments and other engineering structures has been described.

Heshan et al. (2018) suggested a new method for the estimation of crack depth using Make3D tool kit. The toolbox had been used to convert 2D images into 3D images. In this method, ground truth values were calculated from the laser scanner and used supervised learning to train and classify the model [31].

Abdel Qader et al. (2003) compared different crack detection methods using Fast Haar Transform, Canny filter and Sobel filter. The transform splits the image into a low-frequency component and a high-frequency component after identifying the edges of the surfaces with the frequency component [32]. Alam et al. (2015) used acoustic emission and correlation to locate cracks, with the latter technique also used to quantify internal damages. The K-means grouping is used for segmenting the image and analysis is done for three different beams [33].

The use of a Gabor filter approach by Salman et al. (2013) enhanced the effectiveness of crack detection. The crack is determined in all directions and 95% precision had been achieved in the proposed method [34].

Dare et al. (2006) developed a method to perform automatic crack detection in concrete structures. The bilinear interpolation method was used to process the crack pixel values and the sub pixels were measured using DOG filter [5]. Hweekwon et al. (2017) proposed a method to detect the cracks in the pressed board. Edge lines were removed and those outcomes are contrasted with the original sample board. With this technique the speed of crack detection and assessment had been improved a lot [35].

Tian Qinggue et al. (2019) developed a system that detects multiple cracks. In the proposed method the first step was combined edge detection and seed growing. The skeleton optimization procedure, which eliminated non-crack parts and returned the crack attributes, came next. The novel method retrieved multiple cracks from the concrete structure. This model distinguished the crack using a mixed input and classified the detected segments depend on the skeleton data. It was very useful in evaluating the solid structures [16].

The detection of crack particles was the subject of a model proposed by Lee et al. in 2009. By using nearest neighbour techniques, micro structural descriptors were identified, and crack features were obtained from the probability function. The edge effect was eliminated by the nearest neighbor [36]. Tang et al. (2016) created a wavelet-based multi-scale model, performed input image segmentation, and took clinical images for the examination. Edges were extracted utilizing WT and help to detail the immobile

property. The technique had grouped all the pictures with Bayes hypothesis and accomplished the great effectiveness [37]. Parida et al. (2018) used a fuzzy clustering approach to extract the local variance features from an input image. The transition features were extracted from the OTSU Technique, and performed segmentation using hybrid method [38].

Aslam et al. (2020) presented a novel method for estimating the dimensions, measures, and shapes of metal flaws. Median filtering was used to eliminate the noise. With the use of CNN, segmentation and recognition of metal damage had been accomplished. A precision rate of 93% [39] had been achieved with the proposed work.

Sinha et al. (2006) introduced a statistical filter for examining the crack. Crack features were extracted with combined image. Cleaning and linking methods are used to segment the crack. They defeated their past work downside in the morphological activity [40]. Saini et al. (2017) provided a model to categorise and identify various monuments. DCNN was used to extract the presentation and the analysis was carried out with various precise perspectives and an exactness of 92% [41] had been achieved. The performance parameter of images for the crack detection which were discussed in the literature had been presented in the following section.

3.2 Accuracy Based Analysis

Thresholding is a basic method of segmentation and detection of the crack. The issue in thresholding is that both noise and crack has been detected as a crack. This is not an efficient method of detecting the crack. An accuracy of approximately less than 75% has been obtained through this. The numerous crack detection techniques are explained, and each technique is assessed by examining its related pros and demerits.

Addel-Qader et al. (2003) discussed the comparison of crack detection in bridge using Sobel, Fast Haar Transform, canny edge detection and Fast Fourier transform. In all the transforms filtering, compression and denoising had been done to remove the noise in the detected output. It had been concluded that the detection of crack using Fast Haar Transform provides more reliable output than other three methods [32].

Sheerin Sitara et al. (2018) used a preprocessing method to remove the noise in an image using wiener filtering. Singular Value Decomposition and Wavelet transform to overcome the non-uniform illumination of images had been proposed here. The length, area, number of cracks, and width of crack were calculated and thereby performing the automatic detection and classification of civil infrastructure techniques. However, using his method fine crack images could not be extracted [42].

Talab et al. (2016) described how to use image processing to find cracks in concrete constructions. The OTSU method had been employed to detect the major cracks and a Sobel filter had been used to remove the residual noise. Detection of minor cracks could not be achieved here [43].

Sankarasrinivasan et al. (2015) proposed combined HSV thresholding with Bottom Hat Transform for detection of a crack in civil structures. Integrated Unmanned Aerial Vehicles and Image Processing methods for crack detection have been utilized in the combined thresholding. This combined method determines both minor and major cracks. However, dimension of the structuring element and threshold value must be optimized

in the entire process [44]. Salman, M. et al. (2015) introduced a novel method to automatically detect the crack in digital pavement images. The crack had been detected using Gabor filter in multidirectional dimension and thus allowed the detection of crack with 95% accuracy. However the computation time increases with the number of orientation [5].

Transform, morphological approach, Skeletonization procedures, and threshold methods are used to identify the majority of cracks. For identifying characteristics of the image, such as the length, width, and direction of the crack, the morphological technique is applied. The Combined method improves the accuracy of detected crack regions.

4 Results and Discussion

Transform, Morphological Approach, Skeletonization Techniques, and Threshold Method were used to detect the majority of the cracks. The shape of the image's features is determined using the morphological technique. The Crack length, width, and orientation are all measured. The discovered crack locations are more accurately identified using the Combined approach. The segmented output from the crack is shown in Fig. 2. Roberts, Sobel, and Prewitts and Morphological approach have greater noise. However, Canny edge detection and combination approaches produce less noise.

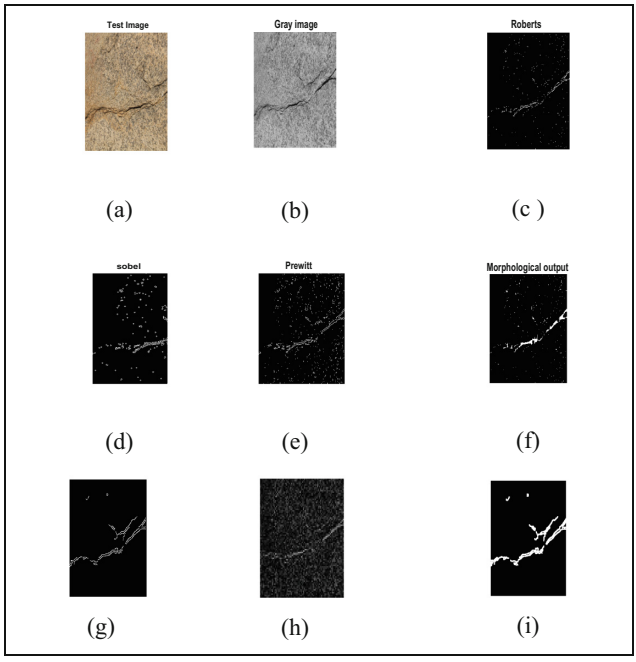

Fig. 2. (a) Input image, (b) Gray image, (c) Roberts method, (d) Sobel, (e) Prewitts, (f) Morphological output, (g) Canny edge detection, (h) BHT, (i) Combined bottom hot transform and canny edge detected

Table 2 compares several crack detection strategies with the suggested strategy employing image processing technologies. The different image segmentation algorithm for the detection of cracks such as Integrated Thresholding, Gabor filter, Enhanced Binarization, Optimized grey processing, Mixture of simple Gaussian density and minimum co-variance, Fast Haar Transform and Convolutional Neural Networks, Supervised approach with CNN was used in all existing method and which produces classification accuracy rate is less than 95% and U^2-Net based Deep Learning model performs pixel-level crack detection and produces 98% accuracy. The Combination of Integrated non destructive methods give better depth of crack than existing model.

Table 2. Comparison between various crack detection nondestructive methods

Existing	Nondestructive methods	Accuracy
Dhital D et al. (2012)	Ultrasonic scanning excitation and piezoelectric air coupled [45]	96%
Wang We et al. (2018)	Infrared thermal imager [46]	96%
Jun Yang et al. (2019)	Infrared thermal using CNN [47]	95%
Feng, Liuyang (2020)	Ultrasonic phased array [48]	Not specified
Aslam Y et al. (2020)	Supervised approach with CNN [40]	93%
Elhariri et al. (2022)	U^2-Net based deep learning [49]	98%

5 Conclusion

In this paper, the theoretical background is explained as per basic concepts from the literature review. In situ, Non-destructive testing (NDT) methods such as image processing methods are most suitable for weathering decay assessment. This method requires less time consumption, and it is user friendly. The depth of the crack cannot be estimated using IRT. The Larger size crack is difficult to analyze using Ultrasonic Testing. The damage severity was not estimated in existing methods. There is a lack of analysis of decay assessment and therefore the assessment of monuments needs more research to reach the ultimate goal of machine simulation of assessment. The deep Neural network method is to be used to structure and validate the results. The diagnostic process for determining the conservation status of building materials and monuments can be improved by the incorporation of non-destructive approaches.

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