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Detection and Classification of Crack for Heritage Building

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Abstract – **Detection, and classification of cracks in buildings are vital to prevent damage and their sudden collapse. This is particularly important to preserve our cultural heritage and save human life. Nowadays, trained operators perform these operations. Consequently, the number of buildings under monitoring is too low and costs are high. Besides the fact that the accuracy and as a consequence the reliability of the inspection results depend on the human operator expertise. For this reason, literature has proposed the implementation of distributed monitoring systems that automatically detect and classify cracks. In this paper, a critical overview of the existent systems and research activities is presented by stressing the metrological challenges.**

I. INTRODUCTION

A crack is a damage in a building that leads to dividing part of the building components into two parts or more [1],[2]. It can likewise be characterized as a line along which material is broken into parts. With time, some cracks begin to show in buildings during their service lives **Error! Reference source not found.**. However, a crack may be the first sign of a severe defect that may affect the building's serviceability or stability [3]. Seldom does a building break down not long after the presence of a crack, but it is fundamental to detect this to prevent the collapse of a building in the future. For this reason, accurately surveying the crack is fundamental [5],[6].

Cracks could be categorized as structural and non-structural. Non-structural cracks are generated by internal stresses in the structure materials and the reasons for these cracks are bad workmanship and improper joint specification. This class of damage is characterized by a depth that is lower, than a structural crack. Instead, structural cracks can arise due to design deficiency, construction deficiency, settlement of foundation [7],[8] reinforcement corrosion, and the effect of temperature variation, overloading, and swelling of soil below the foundation of the structure [9],[10].

It is also critical to evaluate the reasons for cracks through estimation of their qualities, which are location, nature, direction, width, length, depth, and degree of cracks, and how to fix them. Cracks may considerably shift in width from extremely slim hair cracks scarcely noticeable to the unaided eye (around 0.01 mm in width) to expanding cracks 5 mm or more. A generally known classification' of cracks, given their width, is reported in [11]:

- Thin - Less than1 mm in width.
- Medium - Between 1 to 2 mm in width.
- Wide - More than 2 mm in width.

On the basis of this classification, and its meaning for the understanding of crack meaning, the importance of taking measurements of the cracks accurately arises. This paper is focused on measurement methods for the automatic detection of these cracks and finding their features to classify them and determine their severity index for the building's structural health. The final aim is to include the cracks among the parameters used by the distributed measurement system for structural health monitoring [12]. The paper is organized as follows: the first part of paper focused on crack detection algorithms. While the second part focused on classification and finding the characteristics of crack.

II. CRACK DETECTION

The detection of the cracks is the first step to be performed to analyze the crack and find their features. To achieve this step, several detections and classification methods are presented in the literature as shown in Fig.1. Crack detection methods are classified into two main methods. The first method is "static detection" that is, detecting the crack after it has occurred with a period. While the second method is "dynamic detection" which means detecting the crack as soon as it occurs at the same moment.

In the following the analysis method will be described according with the follow classification:

A. Image processing (RGB Image, IR image, Microwave Image, Radar Image, Ultrasonic image).

B. Combination of artificial intelligence and image processing like (Machine Learning and Deep Learning) as known as "Computer Vision"

C. Acoustic emission and Radio-frequency identification (RFID).

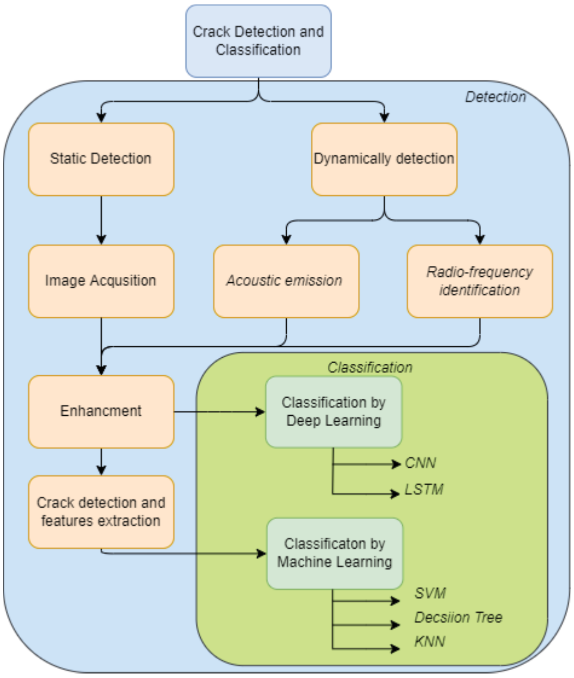

Figure 1: The main classes to detect and classify the cracks

A. Image Processing:

The general design of the crack detection method using image processing is illustrated in Fig.2. The first step of crack detection is image acquisition, which acquires the image of damaged and non-damaged structures. In this step, lightning is one of the main influence factors on image quality, and, as a consequence on the reliability of the detection and on the accuracy with whom the crack characteristics will be evaluated. For this reason, to reduce the lightning effects a light shield or artificial lighting may be used [16]. The resolution of the camera plays an important role in the crack detection technique [17],[18], and its proper chose is vital for the acquisition system effectiveness. Indeed, a higher resolution can help in record more details, but on the other side it increases the cost, the required memory, the computational burden.

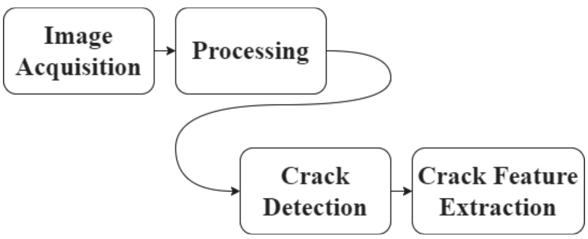

Figure 2: The main steps of crack detection

The next step is the processing stage which is important to reduce the noise in the image and make the crack clearer. The most used image processing techniques are Gaussian filters [19], [20], [21] filters based on the percolation method [21], wavelet transform [22], Canny edge detector [24], and morphological operations [25], [25]. The processing technique should be chosen in such a way that it needs the lowest computation time for the process [27]. A proper crack detection algorithm to recognize the presence and the position of a crack uses the results of image processing.

The main methods of detecting the crack using image processing are:

- Thresholding-based techniques.
- Image Filter techniques.
- Edge detector.

1-Thresholding-Based Techniques:

Usually, the fundamental idea of crack detection is that the pixels that do not belong to a crack have higher brightness than the pixels within the crack region. Therefore, by using the previous consideration it is possible the classify the pixels as a crack and not a crack by thresholding it. To determine the threshold and the operating procedure there are several techniques, in fact, Fujita et al [24] suggested a technique that initially removes the irregular basis lighted conditions and shading effects by subtracting the input concrete image with the smoothened image. After that, Hessian matrix filters are used to give a sharp contrast along the crack edges, which is followed by thresholding to extract the cracks from the background. The advantage of this technique is its stably with changing light intensity, and conditions. This is important because the cracks are photographed under variable lighting conditions. However, the system depends on the threshold value to specify the sensitivity and accuracy.

The accuracy of the threshold-based technique depends upon the choice of threshold values to sight a crack. The generalization of the threshold values is difficult. For this reason, the thresholding techniques could also be unsuitable in a real-time system. Conjointly pixels within the shadow of a part of the image also will have an identical intensity as crack pixels, which can result in inaccuracy in the evaluation of crack parameters.

2- Image Filter techniques:

In the case of structures with textured surfaces, crack detection is difficult as they can be mistaken for the plot of the texture. For this reason, Salman et al suggested an image processing-based approach to detect cracks from pavement images using the Gabor filter. The experimental results showed a detection ratio for the industrial images is 95%.[28]

Yeum and Dyke worked on detection defects from bridge pictures. They notably focused on detection cracks that are beside bolts on steel surfaces. Pictures are captured from varied angles and positions [28]. The region of interest (ROI) is the space close to the bolt however not the bolt itself. Median filter, canny edge detector, and dilate operators are doing it to extract bolts from every image. When removing bolts from the pictures, a Hessian matrix-based methodology referred to as the Frangi filter is applied to detect cracks-like edges.

The detection rate of the system is 98.7%, which leads to a high quality of detection of the crack.

3- Edge detector:

Edge detectors are mathematical techniques that will detect high great contrast in gray levels. At some locations, the gray-level values change, these locations are the edges. The crack creates a high contrast in gray levels these create edges that permits to recognize the crack.

For crack detection, a metaheuristic edge detection model is proposed in [30],[31]. In the paper, a comparison of the performance of the Roberts, Prewitt, Canny, and Sobel approaches is conducted. Roberts, Prewitt, Canny, and Sobel used edge-based techniques to detect the crack textures on walls. To enhance the image, they used median filtering and object cleanup processes. In their proposed model, they get a classification accuracy rate of 89.95% by using Prewitt.

B. Machine Learning and Deep Learning*:*

The crack detection techniques using image processing are limited because is not easy to detect the crack automatically and classify it, for this reason, in the nowadays research it is proposed the use of techniques based on Artificial Intelligence like Machine learning (ML) and Deep Learning (DL) [30],[31].

In supervised ML techniques, a model is trained on a dataset containing features of a crack image. Subsequently, when applying features of the new image to the trained model, it can recognize the crack. In this method, it is necessary to find the features of images and choose the most important features to use during the training step [32]. However, the ML technique in this field has poor accuracy when dealing with complex data. Regarding DL is an evolution of ML that does not need to find the main features characterizing data [25].

The DL most used in the fields of images is the Convolutional Neural Network (CNN). This model has three layers with different functions (see Fig.3): convolutional layer, pooling layer, and fully connected layer. In the first layer, there is an automatic evaluation of

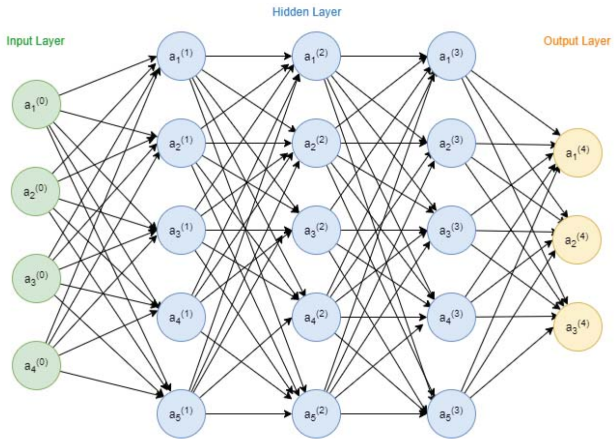

Figure 3: The architecture of neural network.

features from the input, pre-classified images. For this reason, Cha and Choi [33] suggest the use of CNN in crack detection and classification. Moreover, the experimental results show as this method is very suitable in bad lighting conditions.

In particular, the trained classifier recorded accuracies of 98.22% out of 32000 images and 97.95% out of 8000 images in training and validation, respectively.

C. Acoustic emission and Radio-frequency identification:

1-Acoustic emission:

The fracture phenomenon of a material takes place with the release of the stored strain energy, by the formation of cracks, and by the emission of elastic waves/Acoustic Emission (AE). These waves propagate through the material and can be acquired by acoustic emission sensors, as showed in Fig 4 [34].

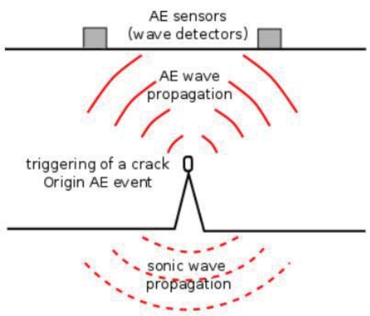

Figure 4: The principle of the acoustic emission.

The features of the AE generated in the crack formation are Amplitude, Duration, Threshold, Rise time, Energy, Count, Average Frequency, RA, b-value, and Ib-value. These features are summarized in (Fig.5). These features are typically used by researchers to understand and classify the cracks.

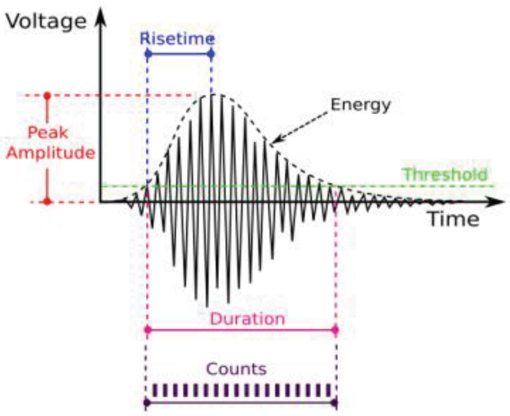

Figure 5: AE impulse parameters

2- Radio-frequency identification (RFID):

RFID technology is composed of a reader that read a specific nearby tag using a radio wave. The RFID tag contains a transmitter with an antenna and chip containing information about the object. The communication distance is from 2cm to 10 m depending on the technology used. Moreover, the reader can read many tags at the same time. In the field of crack detection, the RFID technology is used by mounting several tags on the desired surface as shown in Fig 6. The reader reads the tags periodically. In the case of crack (i) at least one tag cannot be read or (ii) the power received from at least one of them becomes lower than a specific threshold than a crack is detected [35].

III. CLASSIFICATION AND MEASUREMENT CRACKS

To specify the levels of the danger of the crack in the building it is necessary to measure: the length, width, depth, density, and orientation of a crack.

Lins and Givigi suggested a method for the measure of width, length, and angle of the crack [36]. This method is based on image processing techniques that preliminary detect the crack by using statistical filtering and

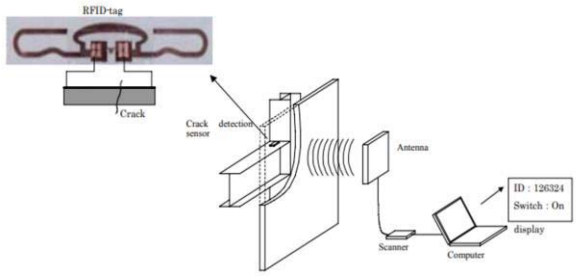

Figure 6: RFID crack detection system [35]

successively determine the width and length of the crack by using a particle filter. To evaluate the angle of the crack they drew a line between any two points on the crack and then used trigonometric rules. The normalized error in the evaluation of the width and length of crack obtained by this method is included between 7.51% to 8.59%.

Instead, Kim and Lee in [37] suggest the use of a profiling algorithm to determine the width of the crack with an estimation error lower than 1%. However, the results are obtained by considering as known the physical dimensions of pixels in the image used in the profiling algorithm. This is not always true. This is mainly caused by the fact that they do not convert the measurement in pixels to real-world ones (i.e., in mm). Moreover, in the paper is not showed an analysis about the effects of different lighting conditions on results accuracy and reliability.

In [38] Carrasco et al proposed a method to determine the width of a crack with more accuracy than concerning the previous methods. The proposed method is composed of three steps as shown in Fig.7:

1. preliminary filtering.
2. adaptive segmentation.
3. profile estimation.

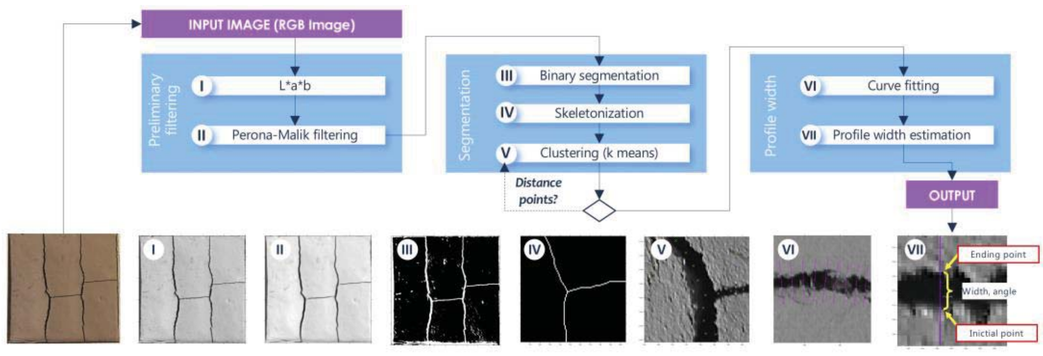

Figure 7: Method to determine the width of a crack [38].

The considered cracks have a width included in the range [0.15, 5.00] mm, with different light conditions. Moreover, the proposed method allows to monitor the width changing of the crack.

In [39] a method for the evaluation of not just the width of the crack, as the previously analyzed methods, but also the depth of the crack is proposed. With this aim, thermal images and machine learning techniques are used. In particular, from the thermal image, the temperature of the crack is evaluated. This temperature depends on the depth of the crack. The temperature is used as an input feature to supervise machine learning techniques (decision tree, extremely randomized tree, gradient boosting, and AdaBoost). In the experimental results, 6490 thermal images were used. These images are artificial crack specimens obtained with known temperature, humidity, and illuminance. The results show that the AdaBoost techniques have better accuracy in the depth evaluation, i.e. up to ±1 and 2 mm.

IV. CONCLUSION

This paper highlights the detection and classification methods of the cracks in buildings, especially as a concern with the heritage ones. The detection techniques are classified as static and dynamic methods. The first class includes methods based on image processing (threshold methods, image filter methods, edge detection methods). The second class includes methods mainly based on the elaboration of acoustic emission and radio frequency identification. The analysis of the literature focuses both on the measurements of cracks' features and their automatic classification by using ML and DL. From this analysis, some gaps in the field arise: (i) no studies or research were devoted to extracting all the parameters of the crack together (length, width, depth, orientation); (ii) few research were presented to evaluate the depth and orientation of the crack and the change in the depth along the crack; (iii) few papers take into account the complexity burden of the measurement process, to allow a real-time evaluation of the cracks. This could be fundamental in an IoT scenario. (iv) few papers deal with the metrological characterization of the proposed methods; (v) the analyzed papers highlight a lack in the homogenization to evaluate and express the measurements, especially as concerned with the uncertainty. This makes difficult the comparison between the proposed methods and consequently the compatibility analysis of the presented results.

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