Crack Detection on Inner Tunnel Surface Using Image Processing

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Abstract. Cracks in the concrete structures such as cracks in the inner surface of tunnels are minor fault, however, can cause major damage or loss of lives if not checked frequently. The current method of detecting cracked surface is manual inspection by hand measuring tools and drawing sheets which may not be feasible as the tunnel needs to be blocked for a limited time period, till the inspection is in progress. By image processing, we can analyze the digital images captured from inside the tunnel for localization of cracks. The algorithm proposed in this paper can be applied to an image of the cracked surface of a tunnel for detecting the crack. Moreover, the length of the crack can also be measured in pixels.

Keywords: Crack detection · Tunnel faults · Surface crack · Image processing · Automatic detection

1 Introduction

Cracks may seem very minor when their formation starts but, it is one of the most fatal defects in concrete structures. The crack increases the stress at a point and as a result, causes damage in the structure. Initially, the cracks may be very difficult to spot with naked eye as it is very thin and hardly visible. Early detection of the crack can prevent a lot of damages from occurring. Some widely used techniques to examine the cracks include Scanning Electron Microscopy (SEM), Infrared (IR) Spectroscopy, and Ultrasonography [1, 2]. However, these methods may not be feasible in various situations because of the complexity of these methods.

Underground tunnels are one of the main ways to decrease traffic congestion in urban cities. However, due to aging, temperature difference, topographic change, tunnels suffer from internal cracks and defects which need to be monitored for health status of the tunnel. Currently, in India, many major cities like Delhi have major metro line connectivity under the ground and require regular inspection and maintenances. Conventional methods of determining cracks are performed manually by hand tools such as measuring

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tools and drawing sheets [3]. These methods have less reliability and it is not feasible as the tunnel needs to be blocked for some limited period for inspection before the tunnel can again function normally. Moreover, quality of inspection can vary from person to person and their work experiences [4]. A person with a good amount of work experience will focus on the elements which require inspection but another person may not be able to do so. Thus, by removing person to person view of crack and improve the crack finding method, we need to create a fully automated crack detection system for more dependable techniques, using image processing [5, 6]. For making the maintenance work faster, it is quite essential to develop some systems that can automatically detect the cracks from the images captured.

The width, length and type of a crack can give a lot of information about the crack and can also determine the duration up to which the concrete can take up the given amount of load at the site of the crack. By using commercial purpose cameras, many images of concrete surface inside a tunnel can be taken efficiently in short period of time. For practical application setups, these cameras with the help of MATLAB can be used for analysis of the cracks.

Image-based crack detection can also face a lot of difficulties. These difficulties mostly arise due to deformed shapes and diverse sizes of the crack, poor lighting in the area and concrete spawl in the image taken. These may result in the detection of various other deformities that might not be present but still comes in the foreground as a part of the crack, reducing the accuracy of the output.

Generally, the time needed for detecting the crack using image processing depends on the size of the image. Since the digital cameras have high resolutions such as 20 megapixels and beyond, these can increase the details of the captured image but subsequently reduce the speed of image processing. Therefore, it is important and required to reduce the hardware cost for detecting cracks efficiently.

Even after overcoming all the possible difficulties, enhancing the image and sheerly highlighting the crack, for better understanding, we could convert the two dimensional (2D) image to a three dimensional (3D) image. It would help us to concentrate on the crack in a very detailed manner, on an additional Z plane which intensifies the crack from the image giving the exact shape and range of the area which need immediate attention.

In this paper, Sect. 2 gives a brief review of related work; Sect. 3 presents the algorithm proposed which would clear up the captured image using various functions; the experimental results with images are given in Sect. 4; conclusion and future work related to this research are given in Sect. 5.

2 Related Work

Crack detection through image processing based method facilitates quick check-up on a large surface area of a structure. Moreover, automated process enables stable and accurate inspection. Currently, crack detection using image processing for inspection of big structures like bridges, pavements and buildings is trending and is under high focus. Image processing based crack inspection techniques have been a point of attention for many researchers. Cracks are fragile areas of a concrete surface, which provides important information for segmentation. Because of uneven lighting, crooked surface and variation of crack types, image segmentation became a compulsory footstep during extraction of crack.

Hutchinson et al. [7] suggested a method to distinguish the crack from the images of concrete by combining wavelet and cranny transform. These image segmentation algorithms can completely extract the edge of a crack under uniform illumination. An adaptive threshold algorithm to solve the image segmentation was also suggested by Navon et al. [8]. A crack identification system was devised by Yu et al. [9] by applying the Dijkstra algorithm to locate the cracks from the pavement. However, the recognition precision was low. Machine vision technology was applied by Sinha et al. [10] to recognize and distinguish the cracks inside a concrete pipe.

3 Methodology

In this section, the key means for detecting cracks is provided. As the traditional methods were not feasible for analyzing the cracks of the tunnel, image processing based analysis is used which provides more accurate results and takes comparatively less time than traditional manual methods [11]. The proposed algorithm is shown in Fig. 1.

First, collect the image of the tunnel surface which will work as the prime subject to crack detection. After image acquisition, the images are pre-processed using few filters and techniques such as median filtering. Finally, the dark areas with potential crack defects are segmented out from background of the gray-scale image by using morphological image processing operations.

The following steps show the general architecture of the proposed algorithm.

3.1 Image Acquisition

The images are acquired from inside the tunnel for crack analysis. The images collected are stored for later or real-time observation of the cracks. General or commercial purpose cameras can be used for capturing the images. An automated system can be used to capture the images.

3.2 Preprocessing Analysis

Image taken from the tunnel is converted to gray-scale image; then it is processed to enhance various aspects of an image such as contrast, hue, saturation by different functions as shown in Fig. 2.

The resolution of the image also plays an important part in finding a crack in an image, if the resolution of the image taken from the tunnel is increased without increasing the quality, the amount of unnecessary data is increased which creates unwanted noise resulting in poor accuracy.

Inside a tunnel, there may be uneven illumination during image capturing, so a low light image enhancement technique is implemented for improving the brightness of the image as per our requirement.

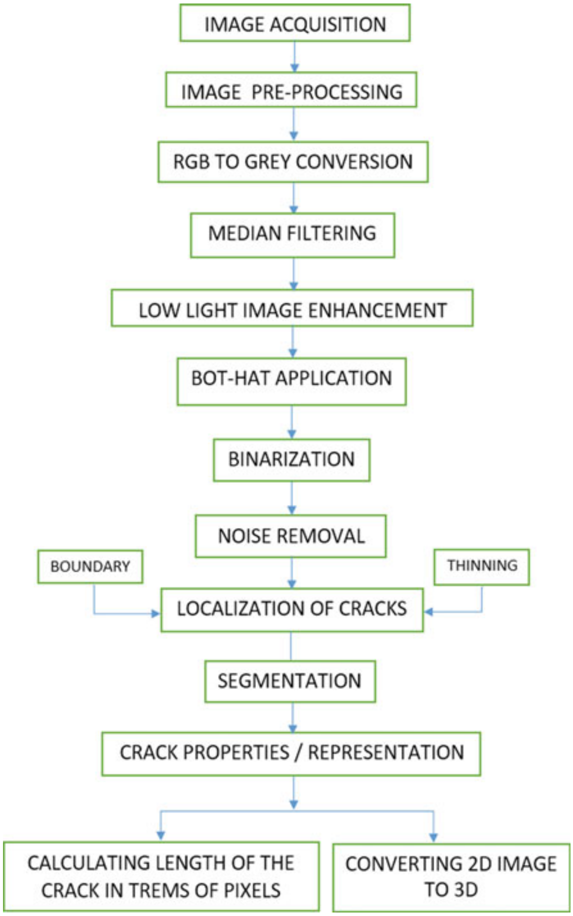

Fig. 1. Flow chart of the algorithm

3.3 Median Filtering

Median filtering is a nonlinear technique used to remove noise from image. It is a very efficient way of removing the noise while preserving the edges. This method works by moving through the image pixels and replacing the target value of the pixel with the median value of the neighboring pixel.

First all the pixel values are sorted from the window in numerical order and then changing the pixel value with the median pixel value. Moreover, the median value should be the value from one of the adjacent pixel, so the values created after this filtering is not unrealistic.

3.4 Enhancement by Bottom–Hat Function

The proposed algorithm uses bottom-hat function which enhances dark spots in a light background. It subtracts the morphological close (joins the circles in an image together

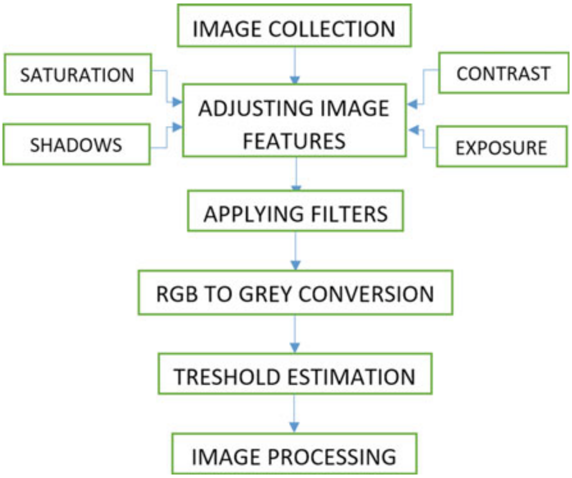

Fig. 2. Flowchart of pre-processing

by filling in the gaps between them) of the image, fills the holes and joins nearby objects. Bottom-hat is an operation performed in order to highlight all the unlighted regions in different images. Bottom-hat efficiently flips high-frequency regions.

In image processing, bottom-hat transforms are extensively used for performing several tasks such as feature extension, image enhancement, background equalization, etc. Using Bottom-hat transform in an image, it is possible to obtain details such as the edge, surface. This process allows extracting the dark features.

3.5 Binarization

Binarization is used for separating background from crack as the gray value of the background is higher than the crack. There are two major problems that arise from this method:

1. Some gray value in the background can be similar to the crack making some objects difficult to detect from the crack.
2. Many unwanted objects such as wires, pipes and other objects may be present which causes interference in the image.

Therefore, it is important to solve these problems. For this, we calculated the average value of T using the N $\times$ N adjacent pixel value surrounded by pixels and set a threshold A.

$$S(a, b) = \begin{cases} 0, & T(a, b) < T - \Delta \\ 255 & T(a, b) \geq T - \Delta \end{cases} \quad (1)$$

$S(a, b)$ stands for the processed image; $T(a, b)$ stands for the original image; and Δ is the threshold.

3.6 Noise Removal

After the process of binarization, noise can be present in the images in different forms which also need to be removed such as:

1. Uneven illumination or background structures in the tunnel may have higher gray value than that of crack.
2. The gray value of pipes, wires and other structure is low as compared to the background and they take up much greater portion than the crack.

Noise removal is followed to overcome the above interferences, i.e. looking for connected black pixels. As gray value of some facilities such as pipes, wires inside a tunnel are low and concentrated. According to this feature, the noise is removed by converting the gray value of the other disturbances to zero. Moreover, the width of any crack does not exceed a fixed amount of threshold. If the adjacent pixels are located in dark region having a width greater than the fixed threshold, then that region will be removed.

3.7 Skelton Function

This process is further used for calculating the length of the crack in terms of pixels. By using pixels in an image, estimation of crack length can be done if the value of pixels denoting millimeter (mm) or meter (m) is known in real life.

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3.8 Pixel Length

By using measurement function, length of a crack in a particular image can be interpreted in terms of pixels. If the number of pixels representing real-life mm or m is known for a particular image, then an approximate length can be measured for the respective crack.

3.9 3D Representation

For having a better understanding of a crack, we convert the two-dimensional (2D) image into three-dimensional (3D) structure. The 3D view can project the crack in an additional plane (z), in this, only the pixels denoting the cracks are intensified and is shown escalated in an extra plane.

4 Results and Discussion

In this section, the results of the experiment are presented. The proposed algorithm was implemented in MATLAB 2014a and tested in windows 10. An algorithm for detecting tunnel cracks was implemented which includes a demonstration of cracks while removing all the noise from the background. The nature of the crack depends on the composition of the material, geometry and structural integrity. These features are not consistent thus the cracking behavior of concrete tunnel elements are more complicated than it seems.

The main advantage of this algorithm is getting an accurate and noise-free image of the crack. In order to make our crack distinct, we use the median filtering, bottom-hat technique, binarization to get rid of the surrounding objects. Median filter is used as it efficiently removes the noises and preserves the edges as shown in Fig. 3b.

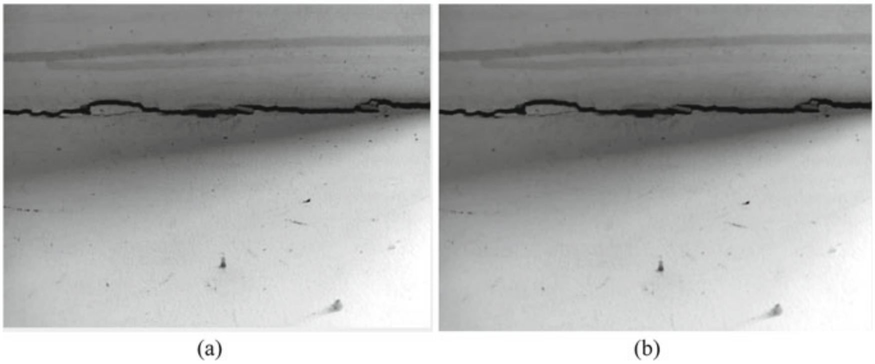

Fig. 3. **a** Original gray image and **b** median filter

We also use low light image enhancement technique to improve the brightness and remove the shadows in the image as per our requirement as shown in Fig. 4a. Bottom-hat function is used to enhances and separate all the dark spots in a light background as shown in Fig. 4b. Binarization is used for separating background from crack as the gray value of the background is higher than the crack as shown in Fig. 4c.

The resultant image is not always noise-free and it may give normal background objects as faults in concrete, as some gray values of the background may look similar to the crack, and thus making it difficult to distinguish the crack from the background. Noise removal is followed to overcome the interferences, which is looking for pixels which less intensity than the crack as shown in Fig. 4d.

The length of the crack can be calculated in terms of pixels, as shown in Fig. 4e for a better understanding of a crack while detection. Moreover, the 2D image is converted into 3D structure. In this, only the pixels representing the cracks are elevated in additional planes as shown in Fig. 5. This may help in analyzing the characteristics of crack just by looking at the 3D view of the graph.

5 Conclusions

In this paper, an efficient approach for crack detection on inner tunnel surface using image processing is proposed. This algorithm's main contribution is highlighting cracks, by an automated crack detection system, which will discard all decision making steps made in traditional methods.

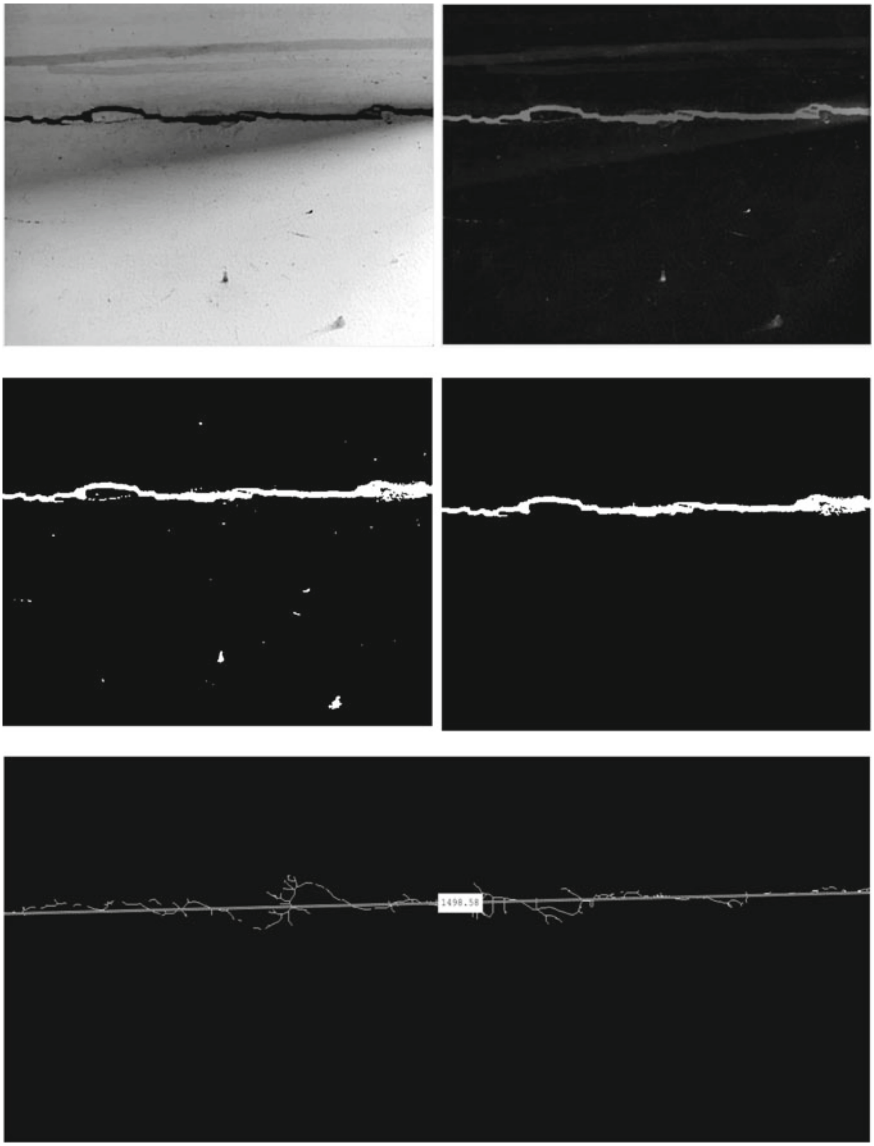

Fig. 4. Illustrations of the procedure. **a** Low lighting enhancement image. **b** Image after bottom-hat process. **c** Binary image. **d** Image after noise removal. **e** Skeleton function and length estimation. Pixel count 1498.58

While simplifying the images by preprocessing, the algorithm makes use of median filter, low-light image enhancement function, bottom-hat function, binarization function and noise removal process for effectively isolating the crack features from other objects or background. Moreover, this paper provides an automated system for measuring the length of the crack in terms of pixel and 3D view of the crack.

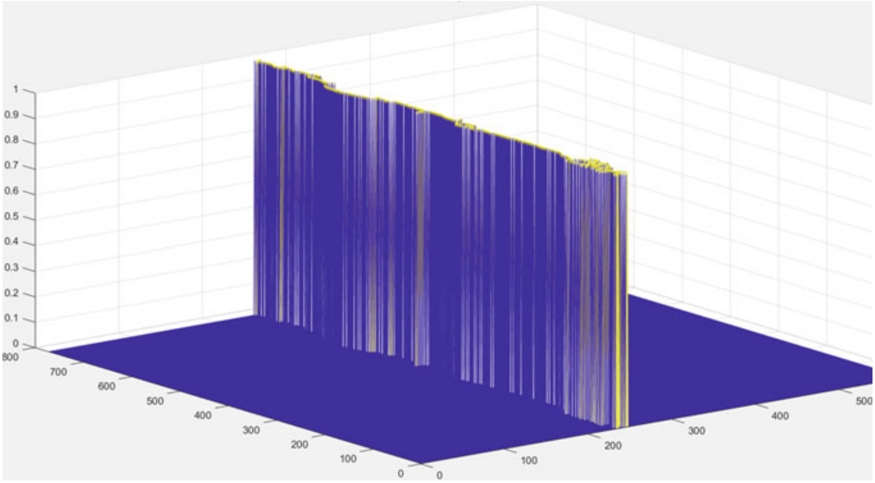

Fig. 5. 3D view of the crack

Proposed algorithm can be easily integrated into many crack detection models as it is relatively straightforward and as demonstrated in experimental results, is capable of delivering precise crack detection. Therefore, this algorithm can potentially be applied by the maintenance department of a tunnel for crack detection and appraisal.

A limitation of this approach is that the users have to adjust some parameters such as threshold in binarization and noise removal for some different types of background features. Our future work will be based on how to remove this limitation.

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