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# Pavement Surface Distress Detection Using Digital Image Processing Techniques

Abdulsalam Basher Alayat* & Hend Ali Omar

*Department of Civil Engineering, University of Tripoli, Tripoli, Libya*

**Corresponding author: a.alayat@uot.edu.ly*

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ABSTRACT

*Road safety and pavement condition are considered top priorities in our civilized societies, and it's important that the pavement condition remains in an excellent state for a long time. However, eventually, the pavement will get exposed to different types of distresses as a result of traffic loads, rough environment conditions, soil conditions, and underline subgrade. Therefore, to achieve the required standards for the pavement surface roads in our country and provide the best performance: detection and measurements of distresses extension must be included in maintenance preparation. This paper proposes a technique for crack detection based on digital image processing using a programming language called Matrix Laboratory known as MATLAB. The main target is to estimate the pavement's length, width, and area by capturing the image using a digital camera with the required precautions and image implementation. Secondly, developing an image pre-processing operation to eliminate environmental interference as much as possible and subsequently use the image thresholding method to separate the pixels within the image into two groups to find the thresholding value for image binarization. The method successfully detects and removes the presence of unwanted objects in an image, even in difficult situations where surfaces are less visible. Verification showed good results with an excellent processing time, which can be considered an indicator of pavement crack parameters.*

*Keywords: Digital image processing; Pavement evaluation; Crack detection; Parameters estimation*

## INTRODUCTION

Pavement condition evaluation is significant for a good pavement management system, effective maintenance, rehabilitation, and reconstruction decision-making. Pavements run in excellent conditions and remain so for a few years without the need for maintenance. However, due to the factor of time, pavements will exhibit distress and their performance will start declining. One of the key components of pavement condition evaluation is the quantification of pavement distress such as cracking, potholes, and rutting. Efforts are presently harnessed to minimize the impact of the distresses on the safety and serviceability of paved roads, which is why it is necessary to accurately measure the width, depth and length of these distresses. Cracks are the type of distress that occur on the surface of pavements. Manual measuring methods are both time and effort-consuming without giving the required accuracy needed in comparison to the automatic techniques that will take less time and effort during the process using digital image processing.

Digital image processing has become economical in many fields like signature recognition, iris recognition and face recognition, in automobile detection and in military applications). Each of these applications has its basic requirements, which may be unique from the others. Image processing has been extensively and successfully used in many sub-areas of civil engineering, such as engineering document scanning, pavement distress assessment, site evaluation via satellite imagery, studies of crack propagation and microstructure in cement-based materials, and evaluation of soil fabric, etc (Dewangan 2016).

The typical pavement management system consists of data collection, data verification and data analysis. A pavement condition survey and analysis provide much of the information necessary for pavement management, and are vital in order to maintain a quantified condition of network, more accurate and accessible information, track performance of treatments, forecast pavement performance, anticipate maintenance and rehabilitation needs, establish maintenance and rehabilitation priorities, and allocate funding. Therefore, it is critical to collect accurate pavement condition data in an efficient and safe manner and to design a reliable analysis system.

The manual collection system is self- validating in the sense that all data are collected by an expert. In automatic collection, data needs to be verified by randomly sampling a percentage of the data and validating it against the actual corresponding pavement. It is critical to go through the alternative evaluation phase which leads to decision making. The following Table (1) contains a comparison between the two methods of pavement data collection, manual and automatic (Rababaah 2005).

TABLE 1. Manual vs. automatic pavement surveys (Rababaah 2005)

| Manual | Automatic |
|---|---|
| Expensive | Extra Expensive |
| Time consuming | Impressively fast |
| Data sampling | Fully survey |
| Subjective | Objective |
| Difficult to manage | Management system linked |
| Poor repeatability | High repeatability |

The image processing technique in pavement crack detection has received remarkable attention since the late 80s. Many algorithms have been provided to detect cracks and used widely in image enhancement, Artistic effects, Medical visualization, Industrial inspection, Law enforcement, human-computer interfaces etc. A quick overview of related crack detection research over the years,

(Cheng et al. 1999) proposed a pavement cracking detection algorithm based on fuzzy logic. The main idea of the proposed method is based on determining how much darker the pixels are than the surroundings by deciding the brightness membership function for gray levels in different images. Second, map the fuzzified image into the crack domain by finding the crack membership values of the pixels. Third, check the connectivity of the darker pixels to eliminate the pixels lacking in connectivity.

(Subirats et al. 2006) presented a new approach in automation for crack detection on pavement surface images, and this method is based on the continuous wavelet. In the first step, a separable 2D continuous wavelet transforms for several scales is performed and complex coefficient maps are built. The angle and modulus information is used to keep significant coefficients. Then, the wavelet coefficient's maximal values are searched and their propagation through scales is analyzed. Finally, post-processing concludes with a binary image that indicates the presence or not of cracks on the pavement surface image.

(Oliveira and Correia 2009) presented a novel framework for automatic crack detection and classification using survey images Acquired at high driving speeds. The resulting images are pre-processed using morphological filters for reducing pixel intensity variance, then dynamic thresholding is applied to identify dark pixels in images, as these correspond to potential crack pixels. Thresholded images are divided into non-overlapping blocks for entropy computation. Afterward, second dynamic thresholding is applied to the resulting entropy blocks matrix, used as the basis for the identification of image blocks containing crack pixels.

(Ouyang, Luo & Zhou 2010) such as image enhancement, image segmentation and edge detection. The noise in pavement crack images is effectively removed by median filtering. The histogram modification technique is a useable segmentation approach, and canny edge detection is an ideal identification approach for pavement distresses.

(Lee et al. 2013) developed an image processing technique that automatically detects and analyses cracks in the digital image of concrete surfaces. The image processing technique automates the measurement of crack characteristics including the width, length, orientation and crack pattern.

## METHODOLOGY

### BRIEF STATEMENT

This method addresses a subset of asphalt crack detection and parameters estimation, specifically the four types of cracks longitudinal, transverse, alligator and block cracks. By implementing the Otsu's thresholding method in different samples. The developed MATLAB code consists of the following phases: image acquisition, preprocessing, crack detection, feature extraction and image representation. The following flowchart in Figure 1 shows the proposed crack detection steps:

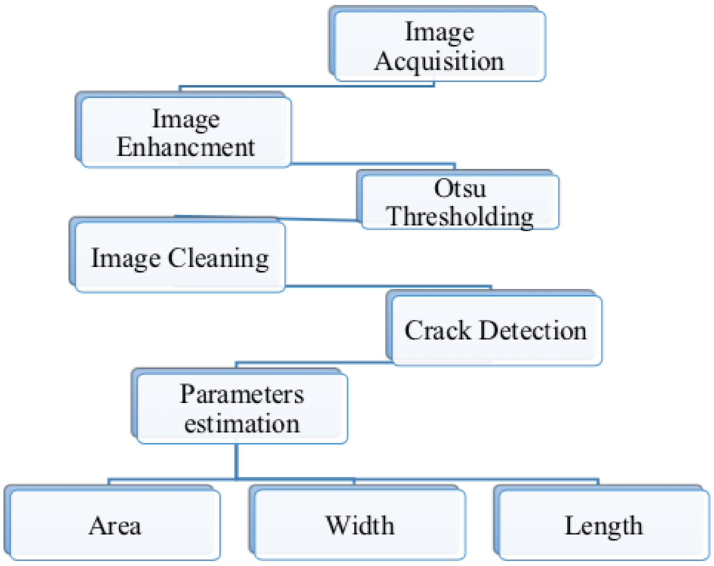


FIGURE 1. The crack detection flowchart

## EXPERIMENT PROCEDURE

In this data collecting procedure, the acquired images were taken by using a digital camera during daylight with its optical perpendicular to the road surface and its lateral edge parallel to the axis. This process was done by using a digital camera, from randomly selected streets and parking lots. Then, we begin collecting colored pictures of different crack types to keep the images in the required standards during the acquisition. To maintain consistent, reliable, and systematic image collection:

*Illumination:* Illumination is important to the quality of the captured images which affects the contrast between the crack objects and the pavement background, therefore we made sure the images were taken during a bright day and at similar timing for consistency.

*Distance from the camera to the pavement:* Maintained the same pavement distance to the camera as much as possible for the entire collection process, since it affects the size of the crack and the relative gaps between crack objects in the acquired image, which is important for the classification process.

*Expert validation:* the data collection technique was consulted and approved by a domain expert.

For the pavement capture procedure, the model of the image acquisition system was installed at the highest point on a portable three-legged tripod (as shown in Figure 2) to support the camera's weight and maintain stability, where the distance between the camera and the pavement was 1.2 meters. The camera had a line of sight of 45 degrees and was capable of coping with a 100x100 Cm square pavement area. Figure 3 shows the image capturing process.

FIGURE 2. The image acquisition model

FIGURE 3. The image capturing process

## EXPERIMENT EQUIPMENT

The image capturing process was performed using Canon EOS 4000D during evening from 7 Pm to 8 Pm to ensure the best quality possible to minimize shadow interruption in comparison to noon time. The original image taken by the camera was flexible to split and resize to achieve balance between real life scale and image dimensions. The captured images had a size of 378×378 Pixels to be analyzed using MATLAB using VAIO laptop, and the verification step was accomplished using a digital caliper and a ruler.

FIGURE 4. CANON EOS 4000D

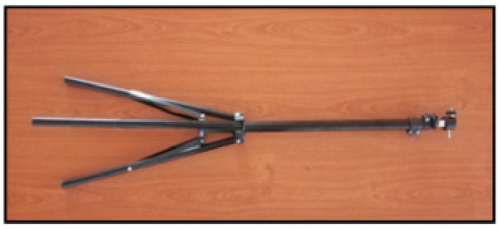

FIGURE 5. Three-Legged Tripod

FIGURE 6. Camera Stick

FIGURE 7. Digital Calliper

FIGURE 8. Useful Instruments Used

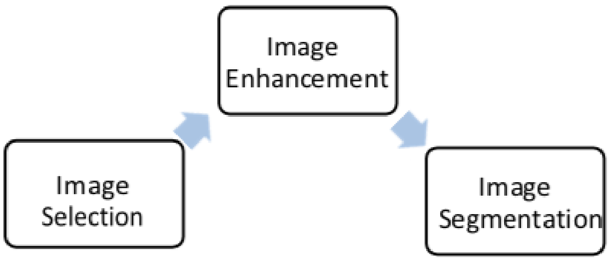


FIGURE 9. Preprocessing Steps

## IMAGE PREPROCESSING

For pavement crack images, useful information exists only in the region containing cracks, but this region is usually quite small compared to the whole image, especially when the pavement condition is in a generally good state. This means that most parts of the image belong to the useless background, which should be excluded from the processing task to improve work efficiency. However, most of the time, the interference from the image shooting environment brings so much noise that it was difficult to distinguish between the useful image regions and the useless background. Therefore, it is necessary to develop an image preprocessing operation to eliminate environmental interference as much as possible. Basically, the images which are obtained during image acquisition may not be directly suitable for identification and detection purposes due to some factors such as noise, weather conditions, poor resolution, and unwanted background which led us to adopt the established techniques and study their performances. Figure 9 shows the main preprocessing steps (Cubero-Fernandez et al. 2017).

## IMAGE THRESHOLDING

The simplest method of segmenting images from a grayscale image. Thresholding can be used to create binary images. To make thresholding completely automated, it is necessary for the computer to automatically select the threshold, histogram shape-based methods in particular, but also other different thresholding algorithms make certain assumptions about the image intensity probability distribution. Automatic thresholding is a great way to extract useful information encoded into pixels while minimizing background noise. This is accomplished by utilizing a feedback loop to optimize the threshold value before converting the original grayscale image to binary. The idea is to separate the image into two parts; the background and the foreground (Gonzalez, Woods & Eddins 2010). The histogram is an approximate representation of the distribution of numerical data to give a rough sense of the density of the underlying distribution of the data. In an image processing context the histogram of an image normally refers to histogram of the pixel intensity values. This histogram is a graph showing the number of pixels.

In an image at each different intensity value found in that image For an 8-bit grayscale image there are 256 different possible intensities, and histogram will graphically display 256 numbers showing the distribution of pixels amongst those grayscale values. Figure 10 illustrates the histogram graph.

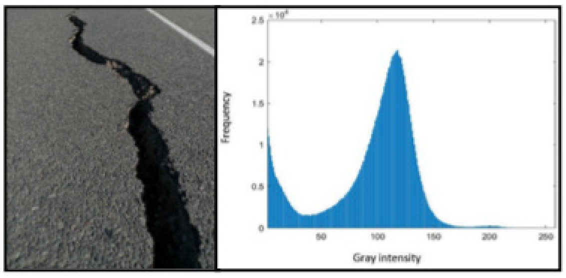


FIGURE 10. Histogram graphical representation

Creating a histogram provides a visual representation of data distribution. It can display the frequency of the data values and show the number of pixels in an image at each different intensity value found in that image. A histogram is a useful tool for thresholding since the information contained in the graph is a representation of pixel distribution that can be analyzed for peaks and valleys to find threshold values, then be used for image segmentation (Fisher et al. 2003).

## OTSU METHOD

Otsu's method is a commonly employed image in the thresholding technique. The basic idea of this approach is to separate the pixels within an image into two groups. The separated object is featured by ω and σ which are the ratio of the number of pixels and the average gray level (Otsu 1979). In a similar manner, the background of the image also has two parameters: ω1 and μ1. The total mean gray level of the image is defined in Equation (1), where *t* denotes a gray level of the image

$$\sigma^2{}_w(t) = \omega_0(t)\sigma^2{}_0(t) + \omega_1(t)\sigma^2{}_1(t) \quad (1)$$

The aim is to find the threshold value where the sum of foreground and background spreads is at its minimum by iterating over all the possible threshold values and calculating the sum of weighted variances. The optimum threshold will be the one with the minimum within-class variance. The value of the gray level t corresponding to the maximal value of σw is selected as the thresholding value for image binarization.

## MEASUREMENTS CONCEPT

The idea is analogous to rotating a spring-loaded Vernier caliper around the outside of a convex polygon, every time one blade of the caliper lies flat against an edge of the polygon, it forms an antipodal pair with the point or edge touching the opposite blade. The complete "rotation" of the caliper around the polygon detects all antipodal pairs as shown in Figure 11.

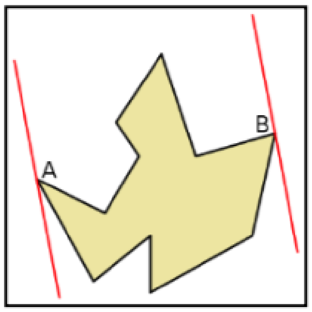


FIGURE 11. Antipodal pair of irregular shape

The method of rotating calipers can be interpreted as the projective dual of a sweep line algorithm in which the sweep is across slopes of lines rather than across x or y coordinates of points. Performing dimensional inspections on complex parts have been a tricky process that has involved everything from hand gage measurement to sophisticated optical systems. This process can be difficult and time-consuming, especially when holes, anchors, braces, and other items must be located precisely on surfaces with irregular shapes (Toussaint 1983).

## RESULTS AND DISCUSSION

The research has been implemented in MATLAB version 9.8 (R2020a) with Image Processing Toolbox. The image processing was performed on Intel Core i7-3537U 2.00 GHz CPU with 6GB of RAM.

### RENDERED SAMPLES

The method successfully detects and removes any presence of unwanted objects in an image, even in difficult situations where surfaces are less visible. The effectiveness of this method was verified on four pavement images that were collected from local roads, and prepared to test the reliability of the proposed system, also used for the crack analysis and dimensions extraction. The result is reported in all testing images figures, the crack pixels revealed by the proposed technique are clean and well separated from the surface structure. Examples of pavement images for longitudinal cracking and the effective steps based on Otsu's algorithm. Figure 12 shows the sites location while Figures 13,14,15 and 16 show the crack detection for each sample:

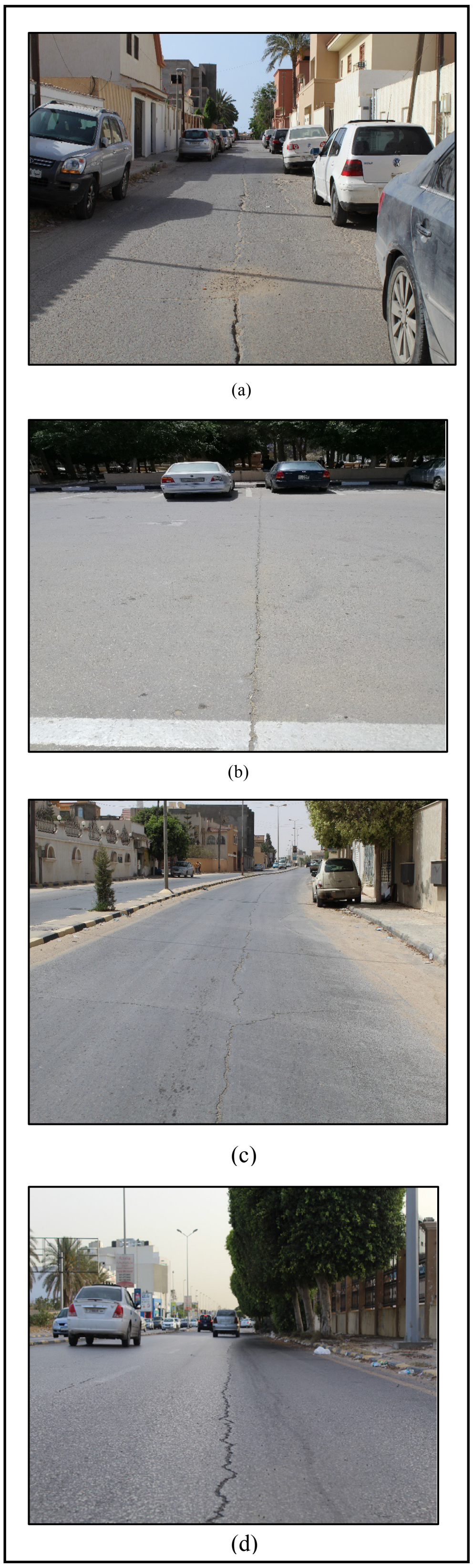


FIGURE 12. Site views for each sample (a) Sample No.1 Hay Al Andauls – May 19th – 07:14 PM (b) Sample No.2 University of Tripoli – May 27th – 05:56 PM (c) Sample No.3 Janzur – June 18th – 07:08 PM (d) Sample No.4 Al Seyaheyya – June 27th – 07:54 PM

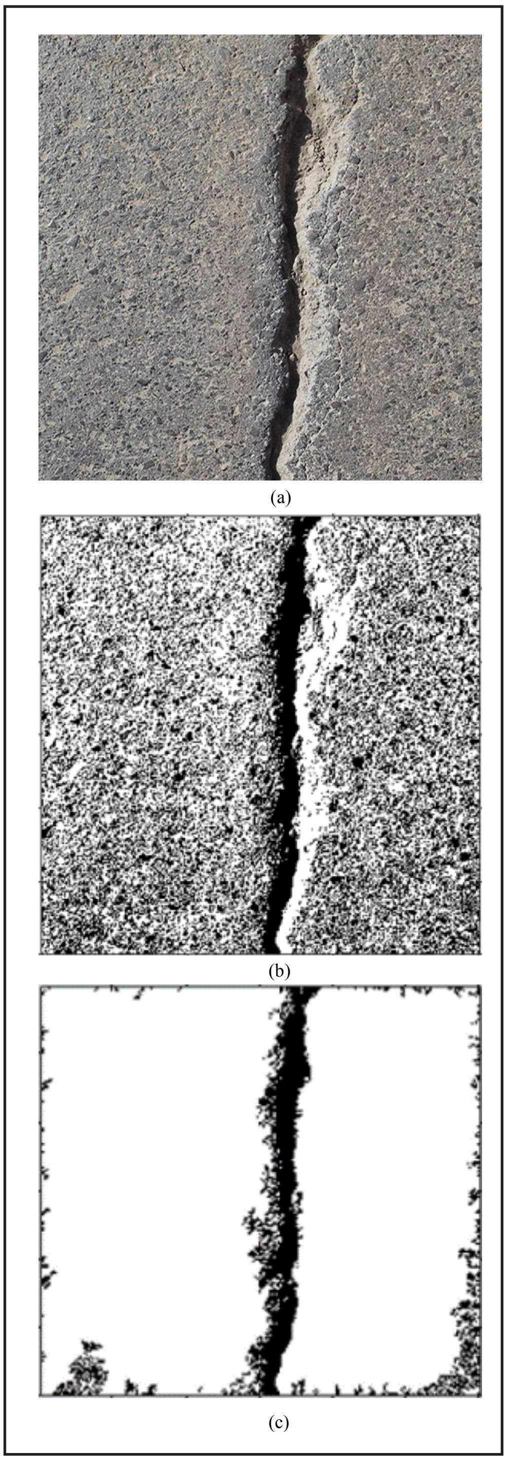


FIGURE 13. Crack detection for sample No.1 (a) Original image (b) Initial binary image (c) Hole filled image

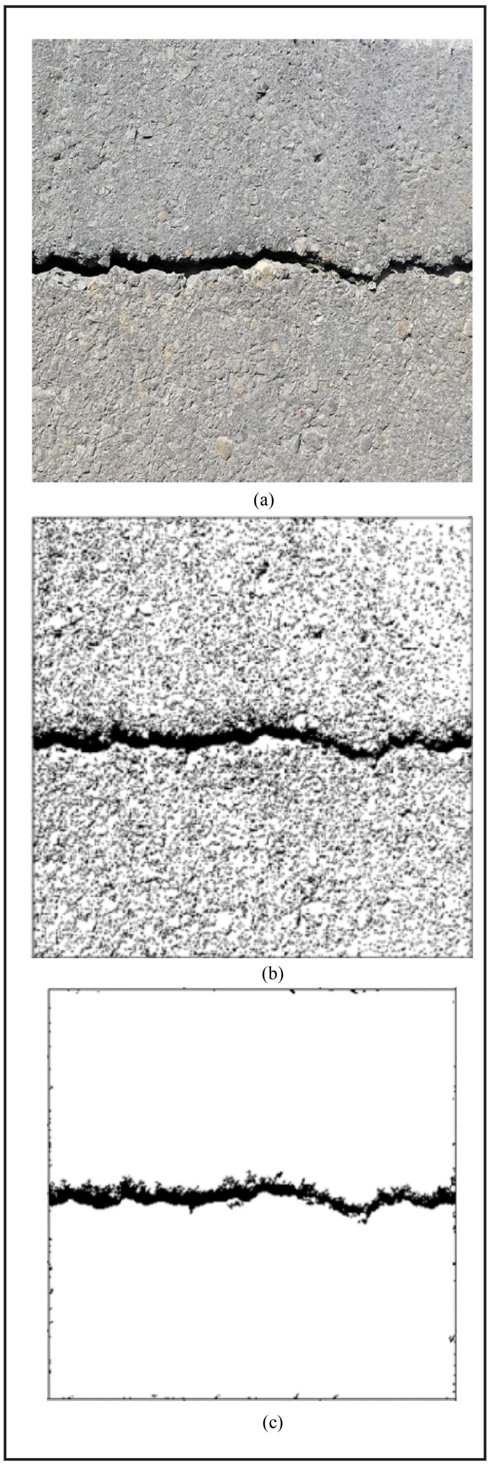


FIGURE 14. Crack detection for sample No.2 (a) Original image (b) Initial binary image (c) Hole filled image

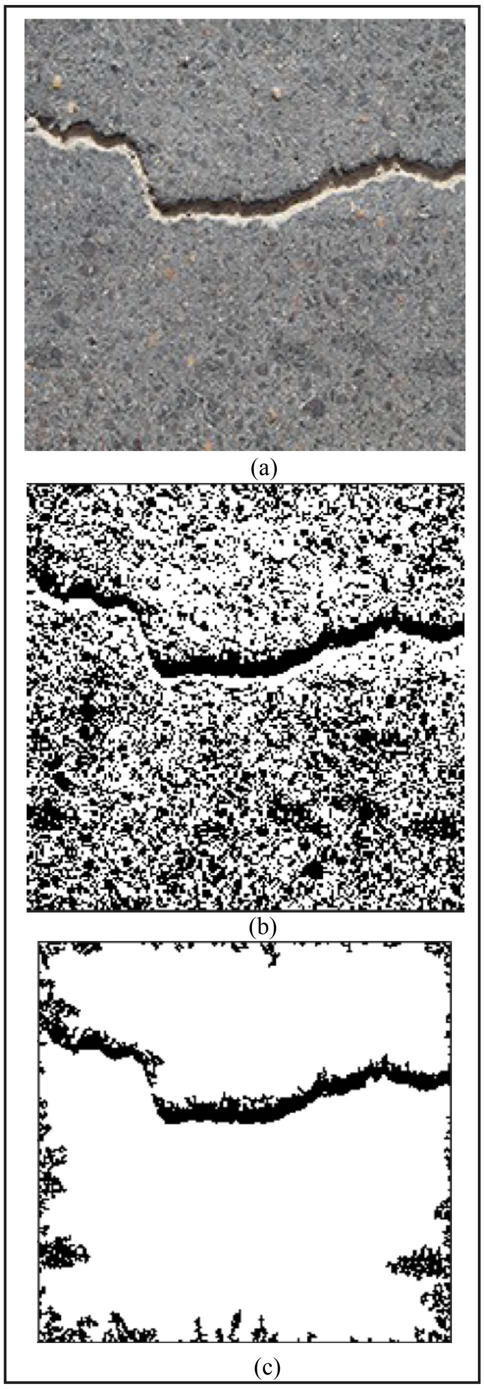


FIGURE 15. Crack detection for sample No.3 (a) Original image (b) Initial binary image (c) Hole filled image

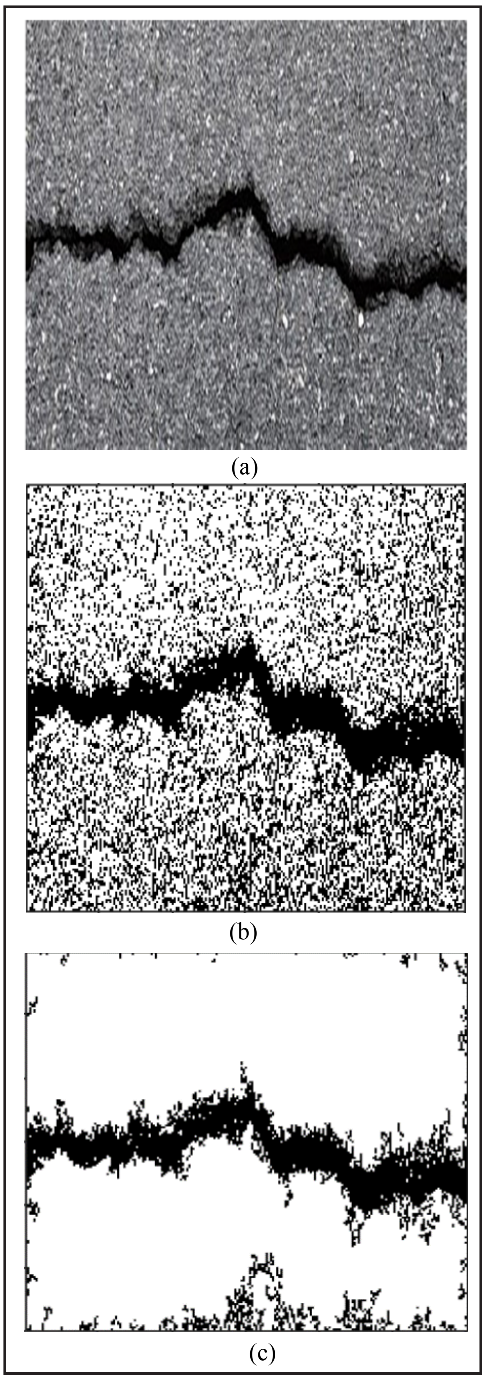

FIGURE 16. Crack detection for sample No.4 (a) Original image (b) Initial binary image (c) Hole filled image

The parameters estimated from proposed technique for each sample are shown in Table 2:

TABLE 2. Parameters estimated

| Sample No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Crack Width (cm) | 1.8 | 2.1 | 3.2 | 1.7 |
| Crack Length (cm) | 54.9 | 55.4 | 69.8 | 53.6 |
| Crack Area (cm) | 98.8 | 119 | 53.6 | 95.1 |

## VERIFICATION

During the development of this technique, several tests were performed on crack images taken with a digital camera to demonstrate the validity of the proposed algorithms. Four crack images were examined in the previous section (Rendered Samples) to a manual test performed on the crack width and length in order to verify the performance of the developed technique by using a Digital Caliper to measure the actual crack width at several points, and a ruler to measure crack length. The accuracy of a measuring technique using image processing and a relevant device depends on the resolution which is determined at image acquisition. There was little difference in the test conditions and the error between the widths and lengths was defined by the following equations (2) and (3):

$$Error\ Precentage = \frac{|w_c - w_m|}{w_m} \quad (2)$$

$$Error\ Precentage = \frac{|l_c - l_m|}{l_m} \quad (3)$$

Where:

| | | |
|---|---|---|
| *Wc* | = | the crack width calculated by the proposed technique. |
| *Wm* | = | the crack width measured by the digital caliper. |
| *Lc* | = | the crack length measured by the proposed technique. |
| *Lm* | = | the crack length measured by the ruler. |

The comparison between the crack width calculated by the proposed technique and the values measured by a digital caliper is provided in the width comparison table:

TABLE 3. Width comparison

| Sample No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Wc (cm) | 1.8 | 2.1 | 3.2 | 1.7 |
| Wm (cm) | 2.6 | 2.2 | 2.3 | 1.6 |
| Error (%) | 31 | 3 | 38 | 10 |

The comparison between the crack length calculated by the proposed technique and the values measured by a Ruler is provided in Table 4 length comparison:

TABLE 4. Length comparison

| Sample No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Lc (cm) | 54.9 | 55.4 | 69.8 | 55.6 |
| Lm (cm) | 100 | 100 | 100 | 100 |
| Error (%) | 45 | 45 | 30 | 46 |

## PROCESSING TIME

Processing time is critical for accuracy, as it assists the researcher in real-time detection. The average total time conceived in the operation per sample is equal to 4.190 seconds.

## DISCUSSION

As the evaluation of pavement condition is the base of pavement management, the trend toward automatic distresses assessment has been widely spread which is based largely on image processing techniques. Since the digital images taken for crack analysis include various difficulties such as low contrast and uneven illumination for the image analyzing process, this study developed an image processing program using MATLAB for detecting cracks on the surface of pavement roads, relying on the adobe Photoshop enhancement techniques followed by the Otsu thresholding method. The method proved success and was able to analyze cracking images with good consistency and reliability. The study consumes not more than a processing time to detect cracks of pavements therefore, the capability of repeating the same procedure on hundreds of images without failure could be the main key in replacing human manual pavement cracks evaluation. A comparison of digital caliper and ruler crack measurement with the results obtained by the proposed technique can accurately detect cracks, but it differs from the actual measurements due to the following:

No.1 sample shows an undetected small crack along the main crack

No.2 sample is clearly distinguishable from meaningless small holes

No.3 sample shows meaningless small objects on the edges

No.4 sample shows very distinct branch-shaped cracks

## CONCLUSION

A large amount of error was incorporated in the measured crack length due to the scale factor and the use of a ruler which necessitates dividing the crack length into several segments. On the other side, the crack width results obtained by the proposed technique were reasonably close to those measured by the manual method. However, the present results suggest that the proposed technique can provide sufficient accuracy for analyzing the widths of the pavement surface. Hopefully, in the future, we'll use artificial intelligence (AI) programs to predict lengths and reduce the error percentage to 5-10% also further evolve the crack detection algorithm by implying and upgrading electrical motion sensors with the ability to measure depths and more complex branched cracks.

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## DECLARATION OF COMPETING INTEREST

None

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