Investigations of the road pavement surface conditions using MATLAB image processing

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Abstract: In view of the increase in the number of vehicles, there has been a need to devise new ways to conduct rapid assessments of the pavement efficiency and thus, improve road performance. Road performance assessment can be carried out in a variety of ways and can predict the future deterioration of the pavement efficiency. Commonly, pavement condition can be estimated on four portions i.e. surface distress, riding quality, skid resistance in addition to structural capacity. In a pavement maintenance management system, the assessment of pavement surface failures is one of the significant duties for improving maintenance and rehabilitation strategies. Different image analysis and processing techniques using MATLAB programming language code have been sophisticated for discovering of distresses like patches, potholes, cracks etc. on the pavement surface, which is called Automatic Evaluation Of Pavement (AEOP). The goal of this paper is to provide an overview of application of the different image processing techniques for discovering and categories of pavement distresses. The code was trained on more than 360 images to increase the efficiency and accuracy of the diagnosis and was then examined on 40 images and giving results with 77.5% accuracy.

Keywords: Pavement distress, Pavement maintenance management, AEOP, MATLAB Code.

1. Introduction

The quality of roads, their efficiency, their capacity and their spread play an important role in the economic development of any country. It plays a vital role in facilitating the movement of goods within the country or from one country to another through international land link. In Iraq, land transport occupies an important position in the public transport system because it is the easiest, fastest and cheapest way as compared to the other means of transportation.

With the increasing number of vehicles on the roads have emerged the needs for maintenance and rehabilitation of the damaged parts in addition to the preparation of studies in order to develop and find new ways to contribute to enhance the efficiency of the road network in the country. The deterioration of pavement happens due to different agents like traffic, pavement age, material properties, environment, thickness of pavement, pavement strength in addition to subgrade characteristics which influence on the mechanical properties of a road pavement. In a [pavement maintenance management system] PMS, the estimate of pavement surface failures is one of the substantial assignments for improving maintenance and rehabilitation strategies [1].

The main groups of surface failures of flexible pavement roads are [2,3]:

1. Cracking [horizontal, longitudinal, blocks, etc.].
2. Surface distortion or deformation.
3. Disintegration [potholes, etc.]
4. Surface defects [bleeding, etc.]
The kinds of distress under each group are illustrated in table 1.

**Table 1. Types of Distress in Bituminous Road**

| Cracking Surface | Intersection | Deposition |
|------------------|--------------|------------|
| Gage crack        | Rutting      | Potholes   |
| Longitudinal      | Shoving      | Polishing  |
| Transverse        | Cracking     | Swelling   |
| Reflective        | Crack        | Evalution  |
| Diagonal          | Cracking     |            |
| Crack             |             |            |

2. **Objective of the research:**

The main objective of this paper is to develop new automated pothole and crack measurement algorithms to analyze digital images with high contrast and resolution; to accomplish this objective, the following tasks are performed:

a) Develop an algorithm for automatic distress analysis of the digital images.
b) Classify the distress by using artificial intelligence.
c) Feasibility study between traditional method (visual survey) and automatic evaluation of pavement.

3. **Literature review**

Because of rough pavement surface in addition to non-uniform illumination of pavement frames in the movie, road images have a significant quantity of background noises. Neighborhood averaging and median filtering are commonly applied as methods of image enhancement. Segmentation is a process of partitioning a digital image into multiple segments (sets of pixels, also known as super-pixels). Thresholding is the most commonly used technique in image segmentation.

Chan et al. improved a thresholding process depending on statistical parameters of the frames to discover cracks on flexible pavement images. Sample images containing linear cracks in addition to alligator cracks were used to check their improved method. Practical results illustrate that their process could analyse the pavement surface images directly in real.

Liu et al. proposed a novel automatic crack discovery approach depending on segment extention for sophisticated pavement movie frames. By analysis of the relationship between connected domains, unrelaxed segments are connected to form a crack and the character of crack trend could be best used in crack distinguishing. Real pavement surface images are used to inquire the execution of this method, and the results illustrate that the surface pavement crack could also be correctly categorized automatically.

Tanaka et al. suggested a new failure detection method in pavement surface image depending on morphological technique. Depends on the idea that cracking is a series of dark dots with the advantage of arranging them linearly. In the suggested method, the discovering of cracks is understood by black color pixel extraction.
Lee\(^9\) proposed a new idea of [Unified Crack Index] (UCI) depending on the image pavement, this idea can be utilized as an overall cracking amount without worrying from a crack kind. With all this, the inspection of a precision crack kind calculation algorithm continued.

Koch et al.\(^{10}\) offered a method of automatic pothole detection in flexible pavement images. In this proposed process an image segmented into fault and non-fault zones by using histogram shape dependent on thresholding. Depending on the geometric properties of a failure area the prospect pothole shape is bordered utilizing morphological thinning and elliptic regression. Thereafter, the surface texture inside a prospect defect form is extracted and matched with the surface texture of another surrounding areas non-defect surface pavement in order to calculate if the zone represents a real pothole. The code is prepared using a methodology of a [MATLAB] prototype. The code was trained and tested by using 120 images of pavement. The results illustrated that the method can distinguish potholes in flexible pavement frames with acceptable precision.

4. The suggested system: -
The system suggested in this paper is a surveillance system algorithm mainly intended for detecting and classifying the distress surface pavement condition. In this study, the work included two MATLAB codes. The first code dealing with movies, tried to use this code to evaluate section of road pavement. The second dealing with images, tried to use this code to categorise the type of 2D pavement distress and determine its severity.

4.1 Movies Processing Code (MPC): -
The code was generated using algorithms and instructions for the MATLAB program. By converting the recorded video to the road pavement face using the high-speed camera to frames, processing, analyzing and determining the type of damage in each image if found and the amount of its intensity. The figure 1; shows the MPC workflow steps. The major steps of the code can be specified below:

- Import the movie from the computer server after changing the type from MP4. to AVI.
- Read the movie by the code by using [videoReader] instruction.
- Convert all selected frames from RGB to Grey scale and after that to double color (black and white). This step is very important to enable the code dealing with just two colors.
- Standardize selected frames to matrices with dimensions (8 rows and 8 columns).
- Calculate the standard deviation of each frame by using (STD) instruction.
- Standardize selected frames to pixels with dimensions (200 × 200) Pixels to make one size for each frame.
- To reduce the noise in the frame, filter the image by using a filter. In MPC and after trying many types of filters, the best filter that can be used is ‘Gaussian’ filter. This type of filter deals with the most of noises in the selected frame.
- To obtain a converging light intensity ratio with range (0.2 to 0.7) to reduce the percentage of error due to variations in light intensity. With this instruction, if the intensity lower than 0.2 will be processed to rise to 0.2. On the other hand if the intensity of the selected frames is greater than 0.7 will be reduced to 0.7. This instruction is [imadjust].
- In order for the good pavement to be distinguished from the damaged area in one picture, the colors are turned to reveal the affected areas in good white and black for the normal pavement.
- Extract the edge value of each pixel in the image using the Sobel algorithm. There are many algorithms that perform the same purpose, but the experiment found that the Sobel algorithm is the most efficient for the type of images used.
- Determine the summation of edge values for each column and also the summation of each row in the selected frame.
- Compare the values of summation edges to determine the type of distress in the selected frame.
The severity of the damage is calculated in the pavement by calculating the ratio of white to black in the selected frame, thus, determining the level of severity of the failure. In MPC divided the level of severity to low, medium and high in addition to mentioning the percentage of failure.

The code was trained on more than 360 images to increase the efficiency and accuracy of the diagnosis and then was examined on 40 images and gave results with 77.5% accuracy.

![Figure 1. MPC- Method Work](image)

4.2 Image Processing Code (IPC):
As same as MPC, the code was generated using algorithms and instructions for the MATLAB program. This code directly analyzes and processes the image that is supplied through the server. The main task of this code is to determine the type and severity of failure only and cannot assess the pavement condition of a road. The code details are very similar to the previous code but there are some basic differences between the two systems including the data entered and the method of input in addition to the output code and the results obtained. The figure 2 shown the IPC workflow steps, which are as follows:

- Dealing with image in type JPEG.
- The image can be taken with any type of camera but taking into consideration that the capture is in the parallel direction of the traffic flow and the camera lens is positioned vertically on the pavement surface.
- The photographer must take into account that the image is special only for pavement distress and not to insert parts of the walkways or cars in addition to the need to be careful not to show any shades of people or the camera or trees and buildings in the street.

![Figure 2. IPC- Method Work](image)

5. Tests and Results
5.1 Categories and Severity
To examine the possibility of the program to identify the different images of the types of failures and severity, which was previously trained, was, examined the possibility of the program to identify the types of failure and severity of 40 different failure images have identified the type of failure and the severity of the correct 32 images only. As for the remaining 8 images, the program's errors differed between the failure to identify the type of failure or identify it incorrectly or to give the severity of the failure is not identical with the real severity of the failure.

5.2 Category of Type of Distress
Through the examination and testing of the code used and trained to extract the characteristics of more than 360 images with different failures, but all of the type 2D was examined. 40 different images of the types of failure were diagnosed where 31 images were diagnosed accurately but failed to diagnose 9 images. This means that the program's ability to categorize the type of failure works efficiently at 77.5% (just for categories).

The figures (3, 4 and 5) illustrated of the results of analyzing of one frame for pavement surface failure.
5.3 Percentage of Severity of Distress

Determination of the severity of the failure in the pavement using the code depends on the total color differences within the image after the filter and reduction of the noise level of the image. Since it depends on the color difference in the determination of the damage, it is of low accuracy as the images taken for the face of the pavement which was covered with a layer of dust.

In case of the examination images (40 images), about 31 images have the approximated results to the real results, another nine images have a percentage of severity far from the real percentage of severity. Therefore, the percentage of accuracy for the forty images is about 77.5%. The receptors to detect the percentage of the severity of the failure can be increased by capturing clear images and matching the capture requirements.

5.4 Time of Surveying and Comparison of Results

One of the most important comparisons that should be discussed is the difference in the time required for the survey in each of the two methods. The time for the field survey was calculated by the survey committee and the result was given by them regarding the efficiency of the pavement.

The speed of giving the decision about evaluating the efficiency of the road by the examination committee depends on several factors, the most important of which. The table (2) below illustrated the differences in time consumptions between the traditional approach (Manual vision) and the new approach (AEOP).

- The length of the road segment to be evaluated. As the relationship between the evaluation time and the length of the section to be evaluated is a positive relationship, as the time taken for the evaluation increases with the length of the section to be examined.
- The amount of traffic volume on the segment to be evaluated. By increasing the volume of traffic, the time taken for evaluation is increasing and vice versa.
- The level of expertise of the examination committee and the speed of decision making to evaluate the section of pavement road to be examined. The faster the decision, the less time it takes to conduct an assessment.

Table 2. The consumption time for surveying in each method for each section.

| No. | Section No. | Time of Surveying (minute) |
|-----|-------------|----------------------------|
|     |             | Visual | AEOP  |
| 1   | Sec 1       | 310    | 25    |
| 2   | Sec 2       | 285    | 25    |
| 3   | Sec 3       | 290    | 26    |
| 4   | Sec 4       | 300    | 25    |
| 5   | Sec 5       | 325    | 22    |
| 6   | Sec 6       | 265    | 24    |
| 7   | Sec 7       | 300    | 22    |
| 8   | Sec 8       | 285    | 24    |
| 9   | Sec 9       | 438    | 32    |
| 10  | Sec 10      | 412    | 35    |

In the case of the survey of the road section by AEOP, all the above factors have very little effect on the time required to complete the survey and give results. In addition, the speed of image processing and assessment and decision-making using artificial intelligence is to weaken the speed of decision-making by the human.

The table (2) above shows the amount of time spent in conducting the examination and evaluation and giving results for each of the ten sections that were evaluated previously, where the time was calculated for the nearest minute and from the moment of initiating the evaluation to the moment of giving the decision.

Figure 6. Consumption time for surveying in each method for each section
Depending on the results figure (6) above, the results obtained can be discussed. There is a very large difference in the time needed to conduct a survey for each method where the AEOP method requires less time than the method of visual and a ratio of (89% to 92%) for the ten examination sections of pavement roads. When analyzing the results figure (6), the difference in the time taken to complete the survey in both methods was observed with the increase of the segment area as in sections 9 and 10. Where in the case of long sections, the time taken to conduct the survey in the visual method increases by a very large percentage, while the rate of increase in time for the same increase in the length of the segment is very little in the method of AEOP.

5.5 Cost of Surveying and Comparison of Results

For the survey in visual method, it needs to form a committee of at least three people from road engineers or technicians with long experience in the field of road management and maintenance, and the use of such specialists means the payment of high costs for the purpose of completing the evaluation of the road segment. In addition, an assessment of a whole section of a road may take a relatively long period of time to complete the surveys and to prepare the actual proportions of the pavement efficiency and increase the time period means increasing the cost to accomplish the task.

On the other hand, conducting surveys to evaluate the performance of pavement using artificial intelligence by the method of AEOP does not necessarily require the formation of committees or a number of workers or even competence, it needs one person trained to use the code with the vehicle equipped with the camera. Also, the time required to complete the surveys of long sections is very small compared to the first type of survey, which means a significant shortcut to reduce the amounts spent to complete the work. In addition to a major shortening of the human efforts.

For example, when considering the controversy, the ten sections studied previously are consecutive sections and the survey was conducted continuously as a single section, the length of the survey and evaluation section is 3500 m and the time taken for the survey using visual method is 3210 minutes (53.5 hour). On the other hand, the time to complete the survey and evaluation in the second way is 260(4.3 hour) minutes. Assuming the committee operates six hours per day, it requires 9 days to complete the work, which was completed less than one day using the second method as shown in the figure (7) below.

![Figure 7. The consumption cost for surveying in each method for each section](image)

Through the above figure (7), the difference in costs to accomplish the same task in two different ways is a very big difference. This reinforces the possibility of developing the second method and making it an essential alternative to conducting the survey using the visual method.

6. Conclusion
This paper demonstrates the applicability and benefits of using image processing to measure pavement surface failure. It shows that this technique is effortless and safe and can be implemented in a short time. This technique can replace traditional road measurements, which are tedious, time-consuming, and expose concerned employees to accidents.

The program can be more efficient in diagnosing the type of failure by increasing the number of images trained by the program, making the thresholds adopted by the program more accurate. The characteristics of the camera used in photography and its resolution play an important role in facilitating the program's task in extracting features and determining the type of failure.

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