Comparing the Accuracy of Image Processing Softwares and Conventional Method for Pavement Distresses Measurement

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Abstract

Pavement distresses, such as longitudinal and transverse cracks, potholes, patching, and depressions, can significantly impact road safety and serviceability. Accurate and efficient distress measurement is crucial for timely maintenance and repair. The conventional method involves manual measurement using measuring tapes and rulers, which is time-consuming, high cost, and depends on the rater's experience. Image processing techniques are a modern method for measuring pavement distresses using digital images and image processing softwares. This study evaluates the accuracy of ImageJ and Digimizer softwares in measuring various pavement distress types compared to conventional method. High-resolution pavement images are captured and analyzed using both image processing softwares and manual measurements. The results are analyzed to determine the accuracy and reliability of each method. The results of the study showed that the measurements of the length, width, and area of road distresses obtained using the Image J program, and the Digimizer program were similar to those obtained using the conventional method, with high coefficients of determination R^2 of (0.9999, 0.9999) for length, (0.9257, 0.5397) for width, and (0.9451, 0.9456) for area respectively.

Keywords Pavement distresses, Image processing techniques, Image J, Digimizer, Measuring, and Accuracy

Introduction

Roads are the most widely used transportation method worldwide, but they are susceptible to various distresses due to factors such as heavy traffic, weather conditions, construction materials, and construction methods [1]. These distresses can lead to accidents, reduced ride quality, and costly maintenance and repairs [2]. Therefore, early detection and measurement of pavement distresses are crucial for maintaining a well-functioning highway network [3].

This research performs image processing techniques to measure flexible pavement distresses, including longitudinal cracks, transverse cracks, potholes, patching, and depressions. High-resolution images of common pavement distresses were captured on roads in the Tenth District of New Cairo, Egypt, using a phone camera with specific specifications. The images were then analyzed using the ImageJ and Digimizer softwares to perform measurement experiments and estimate planar measurements such as pothole diameter, patching and depression areas, and crack length and width.

Previous Work

Stripping, a significant form of distress in asphalt pavements, involves the loss of adhesion or cohesion between bituminous cement and aggregate due to moisture damage at the molecular level. Surface cracks, caused by conventional compaction methods, impact the long-term performance of asphalt pavements. Four standard test methods for stripping evaluation were employed to investigate the effect of surface cracks. Additionally, the influence of surface crack direction on mechanical properties was examined. The results revealed a lack of correlation between laboratory-tested samples and field performance. Surface cracks were identified as a major factor affecting the long-term performance of asphalt pavement mixes [4].

The current construction equipment of asphalt pavement often fails to produce high-quality asphalt surfaces, allowing liquid intrusion and potential pollution of soils and water sources. Research has shown that steel drum rollers induce surface cracks that facilitate water penetration. The development of a new compactor, the asphalt multi-integrated roller (AMIR), creates asphalt layers with tight surface textures and significantly lower permeability compared to surfaces compacted using traditional steel rollers. AMIR-compacted surfaces reduce permeability by a factor of 10 compared to steel-compacted surfaces. These findings highlight the role of improved compaction in protecting the environment and reducing water and soil pollution [5].

Cracks, potholes, and seams each have distinct severity indicators (area, length, etc.) but no universal system for controlling them. Countries set their own standards, like USA's simple low/medium/high classification. PAVER offers a potential method for standardized assessment [6, 7].

Developing road extraction method using fused remote sensing data for investigating extraction roads. Furthermore, comparing the classifier methods soft classifiers namely: Neural Network, Fuzzy and hard classifiers namely: Maximum Likelihood, Minimum Distance for classifying fused images. And, produce recent map with road from fused image data of Egyptdat-1, Radarsat-2 and fused images [8].

Laser Version System uses lasers, cameras, and GPS to precisely assess roads, airports, and parking lots. It measures key features like profiles, friction, and deflection, identifies damage based on established standards, and generates reports for effective maintenance planning and budget allocation. This automated system helps optimize resource allocation and ensures safe, efficient infrastructure for all [9].

A new methodology and schemes are developed for faster and accurate procedure to compute gradation of aggregates by using Image Analysis Techniques (IAT) instead of the conventional methods [10].

A low-cost image processing technique for identifying potholes and cracks in pavements was developed using the Fuzzy-C-Means (FCM) algorithm for longitudinal cracks and the Spectral Theory algorithm for potholes. Tested on images of pavements in Bengaluru, India, the technique showed an accuracy of about 80% in detecting cracks and potholes. Validation with actual dimensions revealed a dimension variability of about 0.46. A linear regression model relating actual and detected dimensions yielded an R2 correlation square of 0.807, indicating a strong positive linear relationship [11].

A new method for detecting cracks in 2D pavement images was developed by adapting the weighted neighborhood pixels segmentation algorithm to overcome the limitations of fixed thresholds in noisy environments. The proposed algorithm was tested on 300 images with a variety of noise levels to represent different pavement conditions. The method was found to be efficient in terms of time and cost, taking less than 3.15 seconds to process a 320 x 480 pixel image on a Xeon (R) 3.70GHz CPU processor. This makes it a suitable choice for county-level pavement maintenance projects that require cost-effective crack detection systems. The validation results were promising for the detection of medium to severe cracks, with a precision of 79.21%, recall of 89.18%, and F1 score of 83.90% [12].

Researchers have developed a game-changer for road assessment: an automated image processing technique that identifies and classifies asphalt pavement cracks and potholes. This AI-powered system can not only distinguish between different crack types but also assess their severity. Compared to traditional manual inspections, the technique shines – achieving a 76% accuracy on images and a remarkable 88% on videos. This innovative approach promises significant advantages: saving time and effort, boosting accuracy and consistency, and ultimately supporting proactive and cost-effective road maintenance strategies. [13].

Two deep learning techniques, Faster R-CNN and YOLO v3, were used to automatically detect and classify distresses in high-resolution (1800 x 1200) three-dimensional (3D) asphalt and concrete pavement images. The training and validation dataset consisted of 625 images that included distresses manually annotated with bounding boxes, which represent the location and types of distresses, as well as 798 no-distress images. Data augmentation was performed to balance the class labels and prevent overfitting. YOLO and Faster R-CNN achieved accuracies of 89.8% and 89.6%, respectively [14].

We improved the YOLOv5 model by introducing an attention mechanism to make it more robust and suitable for deployment in embedded devices. We then transplanted the optimized model to a self-built intelligent mobile platform. Experimental results showed that the improved model can effectively identify pavement distresses with a precision, recall, and mAP of 95.5%, 94.3%, and 95%, respectively. This is an improvement of 4.3% and 25.8%

over the YOLOv5s and YOLOv4 models, respectively [15].

Problem Statement and Objective of the Study

The conventional method is time-consuming, high cost, and depends on the rater's experience.

The main objective of this study is try two different image processing softwares namely ImageJ and Digimizer in measuring various pavement distress types and compare their results with the conventional method.

Steps of the Study

1. Selecting the study area

The images were collected in Abdo Hanafia Street, Tenth District, Tenth of Ramadan City, El Sharqia Governorate. The red highlighted rectangle in Figure 1 shows the location of the study area. The street is a flexible pavement with a variety of distresses. This street was badly damaged for years, and the cracks on the street could be clearly identified by visual inspection.

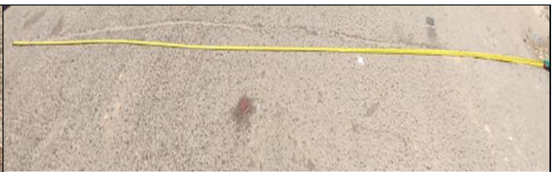
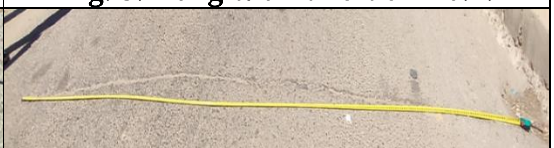
Fig. 1. The location of the study area.

2. Data Collection Using Traditional Method and Digital Images

The length and width of longitudinal and transverse cracks, potholes, and other distresses were measured manually using a tape measure and ruler as follows:

2.1 Measurement of distresses lengths and widths

A. Cracks

	
Fig. 2. Longitudinal crack No.1.	**Fig. 3. Longitudinal crack No.2.**
	
Fig. 4. Longitudinal crack No.3.	**Fig. 5. Transverse crack No.4.**

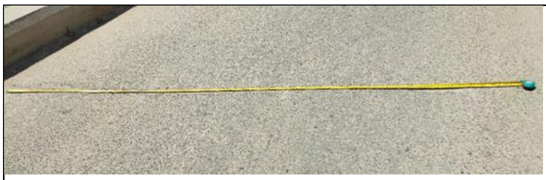


Fig. 6. Transverse crack No.5.

Fig. 7. Transverse crack No.6.

Fig. 8. Transverse crack No.7.

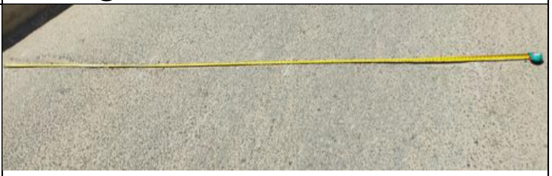


Fig. 9. Transverse crack No.8.

Table 1. Measurements of Cracks

Crack no.	Distress type	Length (cm)	Width (cm)
1	longitudinal crack	970	3.03
2	longitudinal crack	1285	1.46
3	longitudinal crack	139	4
4	transverse crack	500	2.37
5	transverse crack	925	2.43
6	transverse crack	300	2.17
7	transverse crack	456	7.75
8	transverse crack	370	5.75

B. Potholes

Fig. 10. Pothole No.1.

Fig. 11. Pothole No.2.

Table 2. Measurements of Potholes

Pothole no.	Distress type	Length (cm)	Width (cm)
1	pothole	140	34
2	pothole	110	61

2.2 Measurement of distresses areas

A. Depressions


Fig. 12. Depression No.1. **Fig. 13. Depression No.2.**

Table 3. Measurements of Depressions

Depression no.	Distress type	Length (cm)	Width (cm)	Area (cm2)
1	Depression	210	180	37800
2	Depression	150	170	25500

B. Patching


Fig. 14. Utility Patching No.1. **Fig. 15. Patching No.2.**

Table 4. Measurements of Patching

Patching no.	Distress type	Length (cm)	Width (cm)	Area (cm2)
1	Utility cut patching	700	50	35000
2	patching	360	155	55800

3. Applying image processing programs to measure pavement distresses

3.1 Measurements of road distresses using the Image J program

The ImageJ software was used in this research. ImageJ is a powerful image processing software that can be customized to meet the specific needs of users. This was done through the use of plug-in Java classes. A sample of images is shown in the following distresses.

3.1.1 Measurement of distresses lengths and widths

A. Cracks

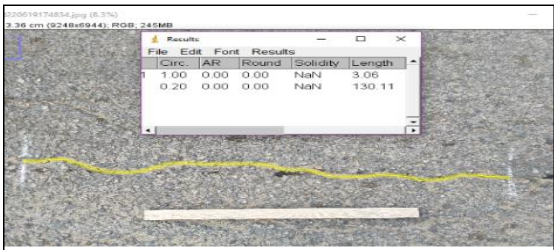


Fig. 16. Longitudinal crack No.1.

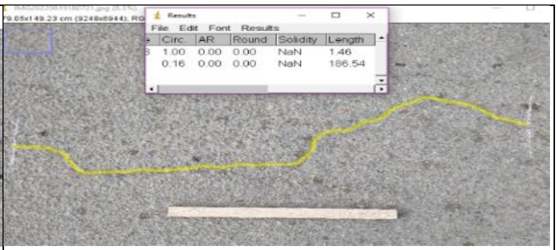


Fig. 17. Longitudinal crack No.2.

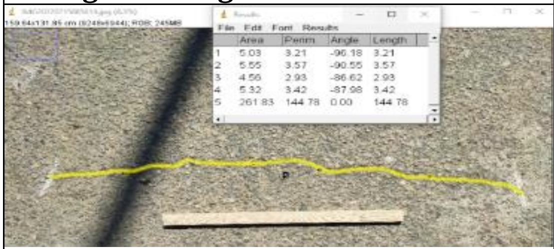


Fig. 18. Longitudinal crack No.3.

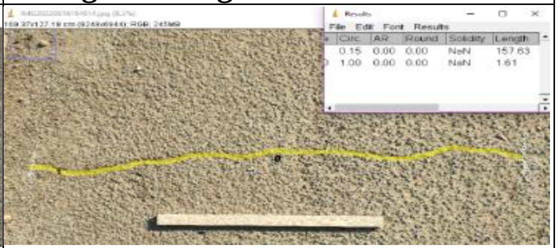


Fig. 19. Transverse crack No.4.

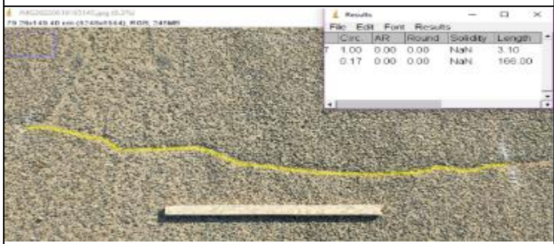


Fig. 20. Transverse crack No.5.

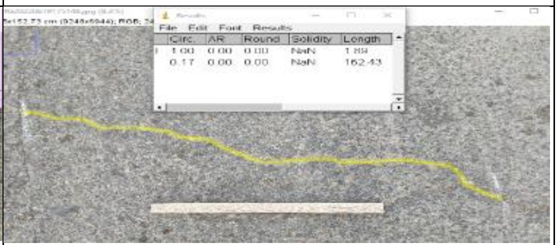


Fig. 21. Transverse crack No.6.

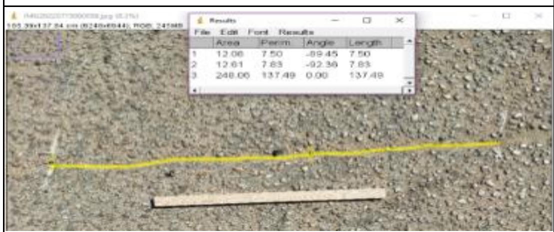


Fig. 22. Transverse crack No.7.

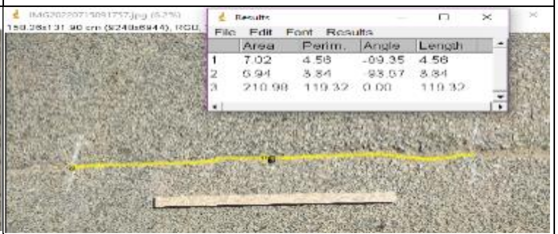


Fig. 23. Transverse crack No.8.

Table 5. Measurements of Cracks

Crack no.	Distress type	Length (cm)	Width (cm)
1	longitudinal crack	995	2.98
2	longitudinal crack	1316	1.42
3	longitudinal crack	145	3.28
4	transverse crack	510	3.46
5	transverse crack	946	2.7
6	transverse crack	317	1.81
7	transverse crack	471	7.1
8	transverse crack	381	5.5

B. Potholes

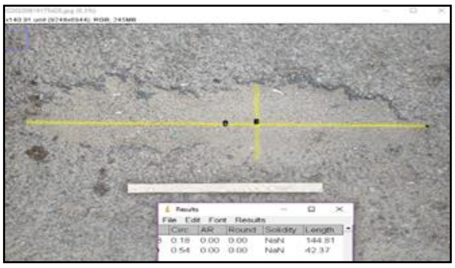


Fig. 24. Pothole No.1.

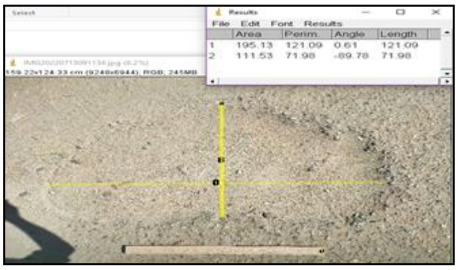


Fig. 25. Pothole No.2.

Table 6. Measurements of Potholes

Pothole no.	Distress type	Length (cm)	Width (cm)
1	pothole	145	42.37
2	pothole	121	71.98

3.1.2 Measurement of distresses areas

A. Depressions

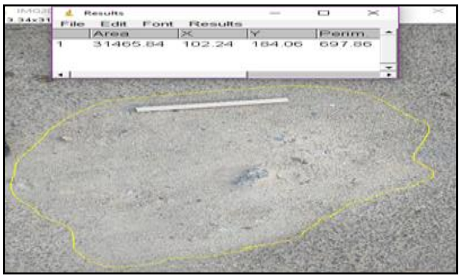


Fig. 26. Depression No.1.

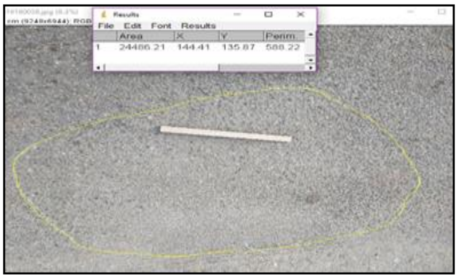


Fig. 27. Depression No.2.

Table 7. Measurements of Depressions

Depression no.	Distress type	Area (cm2)
1	Depression	31465
2	Depression	24496

B. Patching

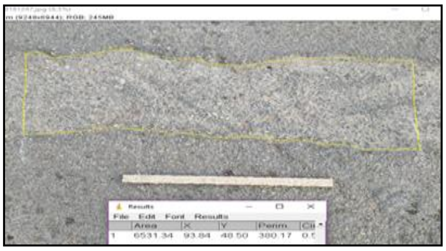


Fig. 28. Utility Patching No.1.

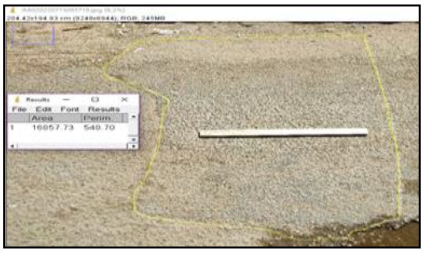


Fig. 29. Patching No.2.

Table 8. Measurements of Patching

Patching no.	Distress type	Area (cm2)
1	Utility cut patching	27500
2	patching	53100

3.2 Measurements of road distresses using the Digimizer program

Digimizer is a software tool for measuring and analyzing images. This program enables users to take precise measurements or allow the program to automatically identify an object in a picture and define its parameters. Digimizer allows for the measurement of distances, perimeters, areas, angles, and the identification of characteristics of circular objects such as ellipses and circles. Moreover, the software can mark and count objects, as well as find and decode barcodes and QR codes.

3.2.1 Measurement of distresses lengths and widths

A. Cracks

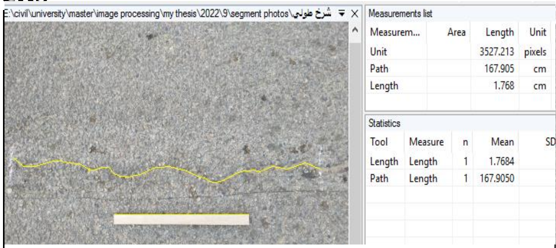


Fig. 30. Longitudinal crack No.1.

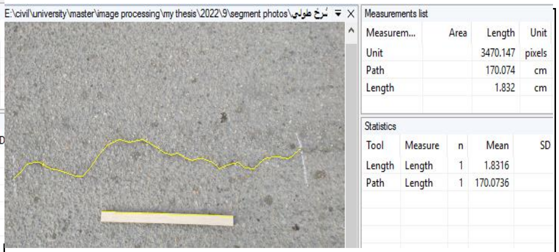


Fig. 31. Longitudinal crack No.2.

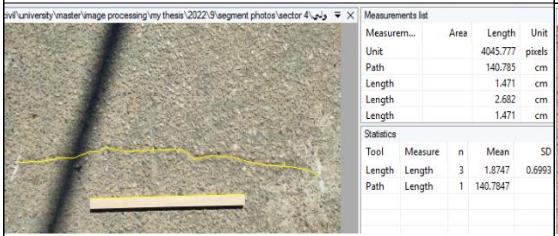


Fig. 32. Longitudinal crack No.3.

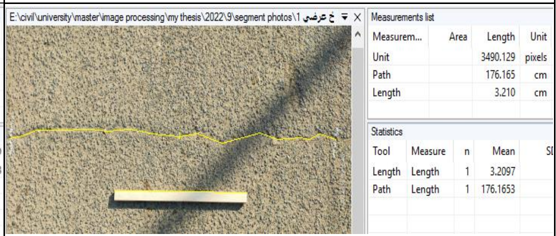


Fig. 32. Transverse crack No.4.

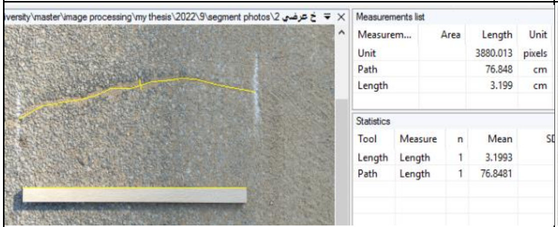


Fig. 34. Transverse crack No.5.

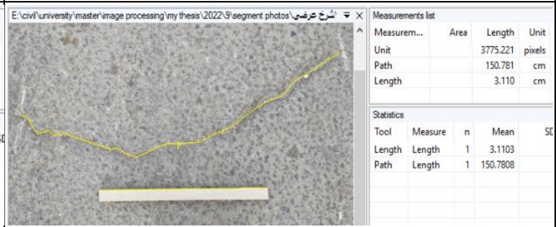


Fig. 35. Transverse crack No.6.

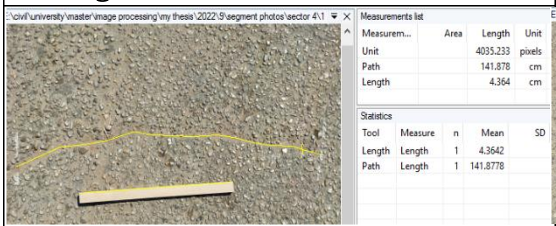


Fig. 36. Transverse crack No.7.

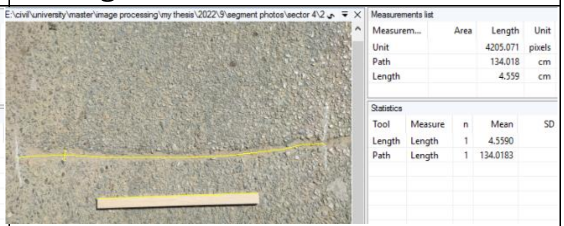


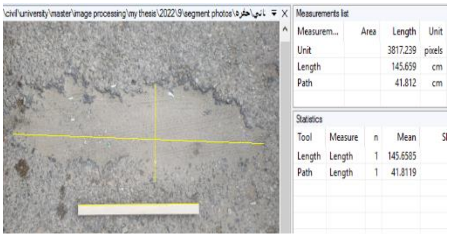
Fig. 37. Transverse crack No.8.

Table 9. Measurements of Cracks

Crack no.	Distress type	Length (cm)	Width (cm)
1	longitudinal crack	999	3.40
2	longitudinal crack	1318	2.40

3	longitudinal crack	141	1.90
4	transverse crack	508	2.90
5	transverse crack	944	2.60
6	transverse crack	309	3.30
7	transverse crack	468	4.70
8	transverse crack	375	5.20

B. Potholes



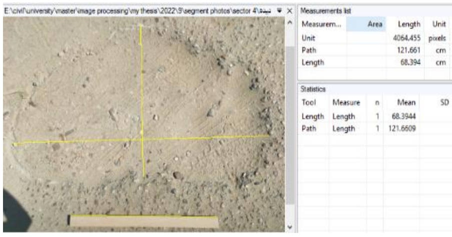


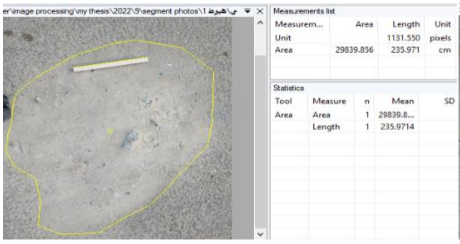
Fig. 38. Pothole No.1. **Fig. 39. Pothole No.2.**

Table 10. Measurements of Potholes

Pothole no.	Distress type	Length (cm)	Width (cm)
1	pothole	146	41.80
2	pothole	122	68.40

3.2.2 Measurement of distresses areas

A. Depressions



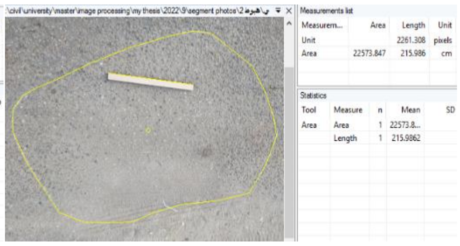


Fig. 40. Depression No.1. **Fig. 41. Depression No.2.**

Table 11. Measurements of Depressions

Depression no.	Distress type	Area (cm2)
1	Depression	29800
2	Depression	22600

B. Patching

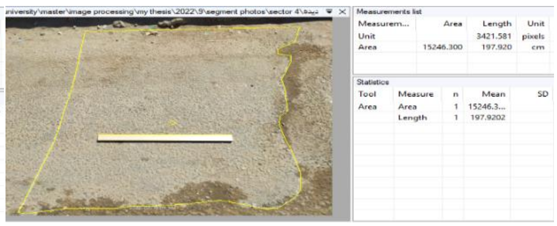


Fig. 42. Utility Patching No.1. **Fig. 43. Patching No.2**.

Table 12. Measurements of Patching

Patching no.	Distress type	Area (cm2)
1	Utility cut patching	24600
2	patching	46100

Results and Discussion

1. Correlation between the measurements of road distresses using the manual method and the Image J program

1.1 Length of pavement distresses

The results showed that the length of distresses measured using the Image J program, and the Digimizer program were greater than that measured by the manual measurement method. This is likely due to the fact that the Image J program, and the Digimizer program are able to detect smaller and thinner distresses than the manual measurement method. The correlation of results obtained by using the Image J program, and the Digimizer program with the manual measurement method showed a high correlation, as indicated by the high coefficient of determination R^2 = (0.9999, and 0.9999). This means that there is a strong linear relationship between the three sets of results. In other words, the results obtained by using the Image J program, and the Digimizer program were closely related to the results obtained by using the manual measurement method. Table 13 and Figures 44, and 45 provide more detailed information about the results. The table shows the length of distresses measured using the three methods for the images in the dataset. The figure shows a scatter plot of the results, with the length of distresses measured using the Image J program, and the Digimizer program on the y-axis and the length of distresses measured using the manual measurement method on the x-axis. The line of best fit for the scatter plot is also shown. The results of this study suggest that the Image J program, and the Digimizer program can be used to accurately measure the length of distresses in pavement images. The high correlation between the results obtained by using the Image J program, the Digimizer program and the manual measurement method indicates that the three methods are producing slightly close results. This suggests that the Image J program, and the Digimizer program can be used as a reliable alternatives to the manual measurement method for measuring the length of distresses in pavement images.

Table 13. The Comparison Results of the Length of pavement Distresses

Distress type	Manual measurements (m)	Measurements of image j program (m)	Measurements of Digimizer program (m)
longitudinal crack No.1	9.70	9.95	9.99
longitudinal crack No.2	12.85	13.16	13.18
longitudinal crack No.3	1.39	1.45	1.41
transverse crack No.4	5.00	5.10	5.08
transverse crack No.5	9.25	9.46	9.44
transverse crack No.6	3.00	3.17	3.09
transverse crack No.7	4.56	4.71	4.68

transverse crack No.8	3.70	3.81	3.75
pothole No.1	1.40	1.45	1.46
pothole No.2	1.10	1.21	1.22
Regression model		y = 1.0191x + 0.053	y = 1.0232x + 0.0145
R^2		0.9999	0.9999

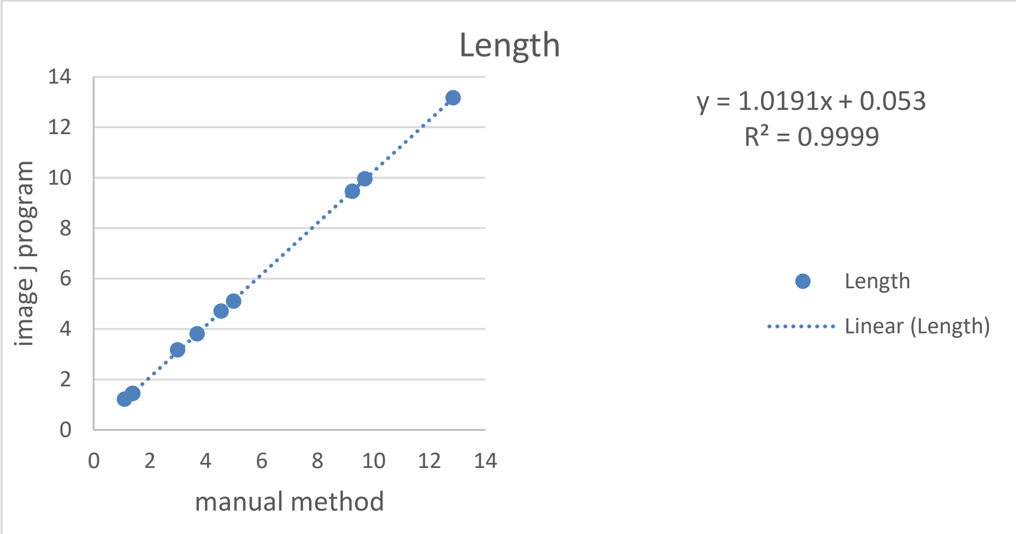


Fig. 44. The correlation between the lengths of pavement distresses measured using the manual method and the Image J program.

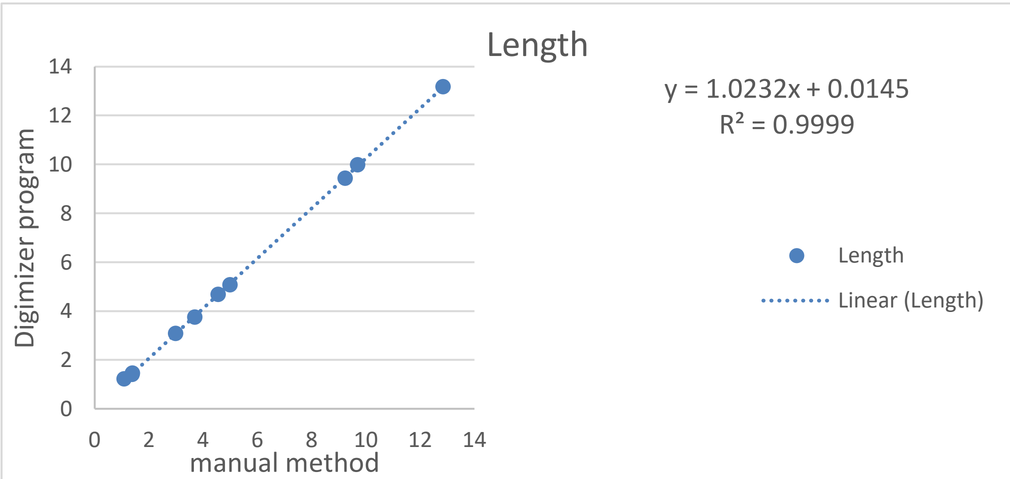


Fig. 45. The correlation between the lengths of pavement distresses measured using the manual method and the Digimizer program

1.2 Width of pavement distresses

The results showed that the width of distresses measured by using the manual measurement method was often greater than that measured by using the Image J program. However, the width measured using the manual method is less than the measurements obtained through the Digimizer program. This is likely due to the fact that the manual measurement method is more subjective than the Image J program. When using the manual measurement method, the human observer may be more likely to overestimate the width of a distress. The Digimizer program isn't accurate because it may have sophisticated algorithms and image processing capabilities that enable to detect and measure distress widths more precisely, leading to larger measurements compared to the manual method. The correlation of results obtained by using the Image J program with the manual measurement method showed high correlation, as indicated by the high coefficient of determination $R^2 = (0.9257)$, and moderate correlation, as indicated by the moderate coefficient of determination $R^2 = (0.5397)$ between the results obtained by using the Digimizer program with the manual measurement method. This means that there is a strong linear relationship between the results of Image J program, and the results of manual method. However there is a moderate linear relationship between the results of Digimizer program, and the results of manual method. Table 14 and Figures 46, and 47 provide more detailed information about the results. The table shows the width of distresses measured using the three methods for the images in the dataset. The figures shows a scatter plot of the results, with the width of distresses measured using the Image J program, and the Digimizer program on the y-axis and the width of distresses measured using the manual measurement method on the x-axis. The line of best fit for the scatter plot is also shown. The results of this study suggest that the Image J program can be used to accurately measure the width of distresses in pavement images. The high correlation between the results obtained by using the Image J program and the manual measurement method indicates that the two methods are producing slightly close results. This suggests that the Image J program can be used as a reliable alternative to the manual measurement method for measuring the width of distresses in pavement images.

Table 14. The Comparison Results of the Width of pavement Distresses

Distress type	**Manual measurements (cm)**	**Measurements of image j program (cm)**	**Measurements of Digimizer program (cm)**
longitudinal crack No.1	3.03	2.98	3.4
longitudinal crack No.2	1.46	1.42	2.4
longitudinal crack No.3	4.00	3.28	1.9
transverse crack No.4	2.37	3.46	2.9
transverse crack No.5	2.43	2.70	2.6
transverse crack No.6	2.17	1.81	3.3
transverse crack No.7	7.75	7.10	4.7
transverse crack No.8	5.75	5.50	5.2
Regression model		$y = 0.8586x + 0.4094$	$y = 0.4047x + 1.8061$
R^2		0.9257	0.5397

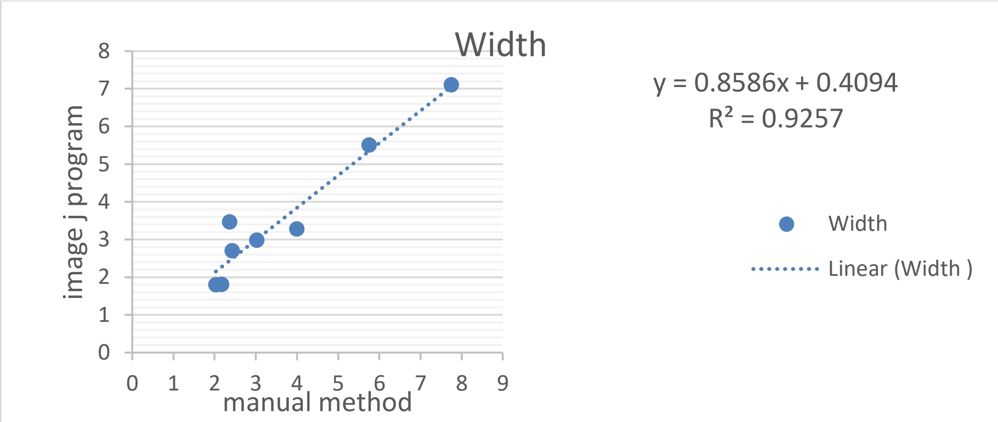


Fig. 46. The correlation between the widths of pavement distresses measured using the manual method and the Image J program.

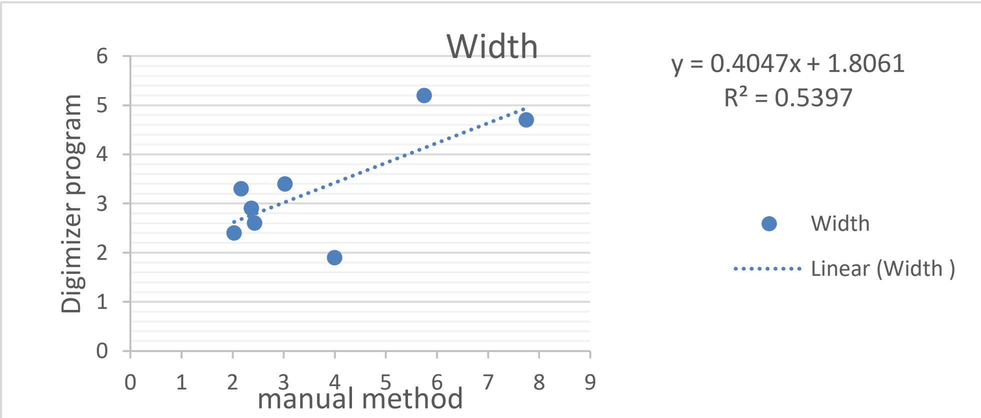


Fig. 47. The correlation between the widths of pavement distresses measured using the manual method and the Digimizer program

1.3 Area of pavement distresses

The results showed that the area of distresses measured by using the manual measurement method was greater than that measured by using the Image J program, and the Digimizer program. This is likely due to the fact that the manual measurement method is more subjective than the Image J program. When using the manual measurement method, the human observer may be more likely to overestimate the area of a distress. The correlation of results obtained by using the Image J program, and the Digimizer program with the manual measurement method showed high correlation, as indicated by the high coefficients of determination R^2 = (0.9451, and 0.9456) respectively. This means that there is a strong linear relationship between the three sets of results. In other words, the results obtained by using the Image J program, and the Digimizer program were closely related to the results obtained by using the manual measurement method. Table 15 and Figures 48, and 49 provide more detailed information about the results. The table shows the area of distresses measured using the three methods for the images in the dataset. The figures shows a scatter plot of the results, with the area of distresses measured using the Image J program, and the Digimizer program on the y-axis and the area of distresses measured using the manual measurement method on the x-axis. The line of best fit for the scatter plot is also shown. The results of this study suggest that the Image J program, and the Digimizer program can be used to accurately measure the area of distresses in pavement images. The high correlation between the results obtained by using the Image J program, the Digimizer program, and the manual measurement method indicates that the three methods are producing slightly close results. This suggests that the Image J program, and the Digimizer program can be used as a reliable alternatives to the manual measurement method for measuring the area of distresses in pavement images.

Table 15. The Comparison Results of the Area of pavement Distresses

Distress type	Manual measurements (m^2)	Measurements of image j program (m^2)	Measurements of Digimizer program (m^2)
Depression No.1	3.78	3.15	2.98
Depression No.2	2.55	2.45	2.26
Utility cut patching	3.50	2.75	2.46
Patching	5.58	5.31	4.61
Regression model		y = 0.9946x - 0.4166	y = 0.8184x - 0.0755
R^2		0.9451	0.9456

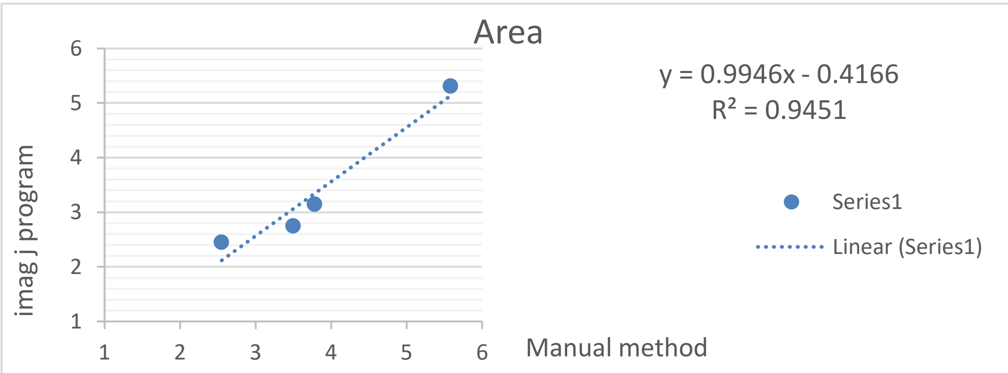


Fig. 48. The correlation between the areas of pavement distresses measured using the manual method and the Image J program.

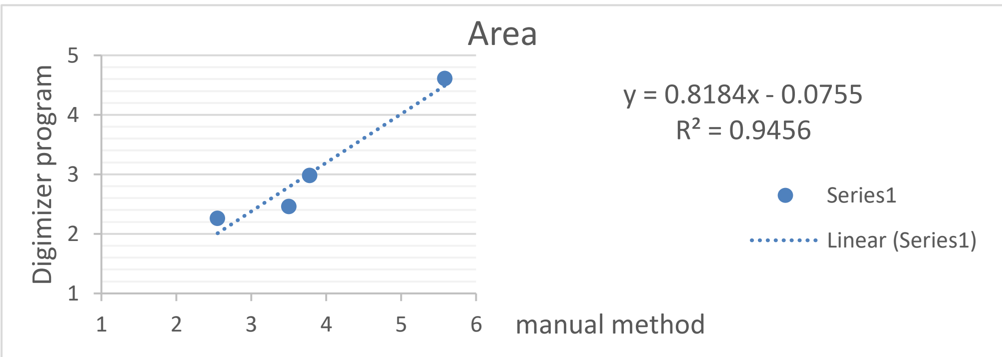


Fig. 49. The correlation between the areas of pavement distresses measured using the manual method and the Digimizer program

Conclusion

1. Image processing techniques are used to measure road distresses using the Image J program, and the Digimizer program.

2. The Image J program, and the Digimizer program are used to measure the length, width, and area of road distresses in pavement images.

3. The image j program, and the Digimizer program are fast image-processing programs, require some experience, and are free.

4. Image processing softwares, ImageJ and Digimizer, demonstrated high accuracy in measuring various pavement distress types compared to the conventional method.

5. The results of the study showed that the measurements obtained using the image j program were similar to those obtained using the conventional method with high coefficients of determination R^2 = (0.9999, 0.9257, and 0.9451) for length, width, and area respectively.

6. The results of the study showed that the measurements obtained using the Digimizer program were slightly similar to those obtained using the conventional method with high coefficients of determination R^2 = (0.9999, 0.5397, and 0.9456) for length, width, and area respectively.

7. The results showed a high degree of correlation between the Image J program with the manual method so the Image J program can be concluded to be the most suitable program for accurately measuring the dimensions of pavement distresses.

8. Image processing methods offer increased efficiency compared to the conventional method, potentially reducing time, cost and resource requirements for pavement distress assessments.

Recommendations

1. Further studies are needed using image processing techniques to measure road distresses.

2. It is recommended the use of close-range satellite images and drone images for pavement inspection, depending on the results of this research and other research. The government should also encourage the use of image processing techniques in the maintenance field.

3. Refine image processing algorithms for even higher accuracy, particularly for complex distress patterns.

4. The next step in this research is to combine 2D and 3D information to create a more reliable real-time system for inspecting pavements.

5. Integrate image processing with geospatial information systems for comprehensive pavement management strategies.

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