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Analysis of Pavement Distresses Using the Image Processing Technique for Egyptian Roads

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ABSTRACT

Roads can experience a variety of distresses due to the combined effects of heavy traffic, weather, the materials used to build them, the underlying soil, and the way they were constructed. Some of these distresses that occur in flexible pavements are longitudinal and transverse cracks, potholes, patching, and depressions. The severity of these distresses increases over time, which has a negative impact on ride quality. To maintain the pavement in a safe and serviceable condition, early detection and measurement of the severity of distresses are required. Image processing techniques are a modern method for detecting and measuring pavement distresses using digital images and image processing software. Traditional methods for measuring distress are laborious, slow, and risky for the measurers. In contrast, image processing techniques are simple, safe, and quick to complete. This research paper performs image processing methods and measurements using two image processing programs, one for detection and the other for measuring pavement distresses. A comparison of image measurements with traditional measurements showed that the two methods are highly correlated, with image measurements being very close to those obtained using the traditional method. The results of the study showed that the measurements of the length, width, and area of road distresses obtained using image processing techniques were similar to those obtained using the traditional method, with high coefficients of determination R^2 of 0.9999, 0.9257, and 0.9451, respectively.

1. Introduction

Roads are the most widely used transportation method around the world at present. One of the causes of accidents on the roads is road distresses. Highways can experience a variety of distresses due to the combined effects of heavy traffic, weather, the materials used to build them, and the way they were constructed [1]. Distresses that affect flexible pavements include cracking of pavement, surface distortion, slippery surface, and disintegration. If left untreated, road distresses will degrade the ride quality and safety of motorists. They will also require costly maintenance and repairs, which can restrict traffic flow and cause congestion. Therefore, timely maintenance is essential to keep highways safe and durable [2].

Early detection and measurement of pavement distresses is essential for maintaining a well-functioning highway network. This allows highway authorities to take quick action to repair distresses

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before they become more serious and costly to fix. The sooner pavement distresses are detected and repaired, the less expensive it is to maintain the highway. This is because early repairs can prevent more serious distresses from developing, such as potholes or rutting [3].

This research performs image processing measurements to identify flexible pavement distresses such as longitudinal cracks, transverse cracks, potholes, patching, and depressions. High-resolution images of common pavement distresses were taken on roads in the Tenth District of New Cairo, Egypt, using a phone camera with a resolution of 64 megapixels, dimensions of 9248*6944 pixels, and a focal length of 5.58 mm. Any camera with the same specifications could be used in image processing techniques.

Image processing analysis was applied using the PCI Geomatica program to detect pavement distresses.

The ImageJ program was used to perform measurement experiments to estimate planar measurements such as the diameter of the pothole, area of patching and depressions, and crack length and width.

2. Previous Work

There are different indicators for the severity of pavement distresses. For example, the surface area unit (length and width) is an indicator for crack detection, patching, and binder enrichment. The area unit (diameter) is a suitable indicator for the detection of potholes, while the sum of lengths is an indicator for the detection of open work seams. Unfortunately, there are no standard specifications and no standard methods for controlling the severity level of pavement distresses. Different countries have their own standards, and in the USA, all cases and indicators for severity levels are classified as low, medium, or high, regardless of depth. The PAVER System Manual is used to classify severity levels [4,5].

The Roadware Automatic Road Analyzer (ARAN) is a high-speed vehicle that can collect a wide range of data about pavement conditions, including images of the pavement, images of the road surface, and measurements of the longitudinal and transverse profiles of the road. Another similar system is the Fugro ADVantage, which is also installed and transported by a vehicle. The Fugro ADVantage was one of the first digital systems for automatic inspection of the pavement. However, a major impediment to using these systems is the cost of acquisition. They are too expensive for many local governments to purchase [6].

Pavement crack detection and classification is a critical task in pavement engineering. It is used throughout the life cycle of a road pavement, from construction to evaluation, performance measurement, maintenance, rehabilitation, and reconstruction. Automatic road inspection and image processing are now commonly used in the maintenance and rehabilitation of roads. These techniques can be used to evaluate cracks, distress, and other types of pavement deterioration [7,8,9].

GeoAutomation™ is an image-based mobile mapping system that uses cameras and GNSS to collect data about the environment. This data can be used to create 3D models, measure distances, and create maps. The system is based on pixel recognition technology, which allows it to accurately identify objects in images. This makes it a valuable tool for surveying and mapping. The standard configuration of the system includes 14 or 16 cameras, each with 2 or 8 megapixels. This allows the system to capture a wide range of detail. The image capturing and processing are done in a pipeline, which ensures that the data is processed quickly and efficiently. The surveying process involves several steps: recording drive-through, 3D reconstruction of recorded images, geo-referencing of the result, surveying and measuring based on the 360° view images into GIS system, and surveying on the web [10].

Automatic road inspection has been a topic of interest for researchers and specialists since the 1990s. The first well-known solution was developed by a group of researchers at the University of Arkansas, who created a specialized vehicle called the Digital Highway Data Vehicle (DHDV). The DHDV uses a combination of GPS, a distance measuring instrument, a gyro sensor, and a power source to provide real-time visual inspection of the pavement system. This includes geopositioning features that allow the vehicle to track its location and the location of any distresses that are detected. The DHDV was a pioneering effort in the field of automatic road inspection, and it has since been used to inspect roads in a number of countries. It is an example of how technology can be used to improve the safety and efficiency of our roads [11].

Laser Version System is a comprehensive solution for managing road networks, airports, and large surface parking lots. It is certified to ISO 90012000 standards and uses laser, camera, GNSS, and DGPS technology to evaluate pavement conditions. The system provides a variety of measurements, including longitudinal and transverse road profiles, road geometry, surface friction, and deflection. It also identifies surface distresses based on North American standards. G.I.E. offers an efficient data collection system and automated equipment for pavement evaluation. The system can generate reports on network condition, maintenance and rehabilitation plans, and multi-year budget plans. All evaluation and historical pavement data are consolidated and analyzed to prioritize maintenance and rehabilitation projects. This ensures that public funds are used effectively [12,13].

Artificial neural networks (ANNs) were used to automatically detect cracks in road pavements from airborne images. The ANN model showed that it was suitable for pattern recognition of road cracks, as evidenced by its high performance parameters. Performance parameters such as accuracy, precision, and recall were used to evaluate the ANN model. The model achieved high values for all of these parameters, indicating that it was able to accurately detect cracks in road pavements. These results suggest that ANNs can be a valuable tool for automatically detecting cracks in road pavements from airborne images. This could help to improve the safety and efficiency of road maintenance and repair [14].

The ability to automatically detect and measure potholes in asphalt pavements will be demonstrated in the near future. This will be accomplished by using 3D reconstruction techniques to analyze images acquired by the ZED camera. The system has been tested on both static and dynamic geometries, and the results have been promising. The metrological parameters of potholes can be efficiently obtained from the images acquired by ZED. This is because the ZED camera is able to capture high-resolution images of potholes, even in low-light conditions. The system testing results have shown that the system is capable of accurately detecting and measuring potholes in both static and dynamic geometries. This is a significant advancement, as it will allow for the early detection and repair of potholes, which can improve road safety and reduce maintenance costs [15].

A low-cost image processing technique for the identification of potholes and cracks in pavements was developed. The technique uses the Fuzzy-CMeans (FCM) algorithm to detect longitudinal cracks and the Spectral Theory algorithm to detect potholes. The technique was tested on images of pavements in Bengaluru, India, and was found to be accurate in detecting cracks and potholes with an accuracy of about 80%. The detected images were validated with the actual dimensions, and the results showed that the dimension variability is about 0.46. A linear regression model was also developed to relate the actual and detected dimensions, and the R2 correlation square was found to be 0.807, which indicates a strong positive linear relationship between the two variables [16].

A novel computer vision approach has been developed to automatically identify rutting on asphalt pavement. The approach uses a combination of image processing techniques, a machine learning model, and a metaheuristic optimization algorithm. First, Gabor filters and discrete cosine transforms are used to extract features from images of rutted and non-rutted pavement. These features are then used to train a Least Squares Support Vector Classification (LSSVC) model to classify images as rutted or non-rutted. To improve the accuracy of the model, a metaheuristic optimization algorithm called forensic-based investigation (FBI) is used to optimize the hyperparameters of the LSSVC model. The FBI algorithm searches for the optimal hyperparameters by iteratively evaluating different configurations of the model. Finally, a dynamic feature selection (FS) method is used to remove redundant features from the model. This helps to improve the accuracy of the model by removing features that do not provide useful information. The proposed approach was evaluated using a dataset of 2000 image samples collected from Da Nang city. The results showed that the approach achieved a classification accuracy rate, precision, recall, and F1 score of 98.9%, 0.994, 0.984, and 0.989, respectively. These results demonstrate that the proposed approach is a promising method for automatically identifying rutting on asphalt pavement [17].

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% [18].

A novel image processing technique was developed for the automatic detection and classification of asphalt pavement cracks and potholes. The technique can identify different types of cracks, including transverse, longitudinal, alligator-type, and potholes. The goal of the research was to evaluate road surface damage by extracting cracks and potholes from images and videos, and comparing the manual and automated methods. The proposed method was tested on 50 images. The results showed that the method can detect cracks and potholes with a medium validity of 76%. The severity levels of the cracks and potholes can also be identified. There are two methods for distress evaluation: manual and automated. The manual method involves visually inspecting the road surface and recording the types and severity of the cracks and potholes. The automated method uses image processing techniques to detect and classify the cracks and potholes. The automated method was assessed by processing videos of the road. The accuracy percentage for this case study was 88.44%, which is higher than the accuracy of the manual method [19].

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 [20].

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 [21].

A computer vision method for automatically classifying cracks and sealed cracks in asphalt pavement surfaces extracts features from images of the cracks. These features are then used to train a machine learning model that can classify the cracks into three categories: noncrack, sealed crack, and crack. Experiments with image samples of asphalt pavement surfaces show that the proposed method is highly accurate, with a classification accuracy rate (CAR) of 90.50% for noncracks, 92.83% for sealed cracks, and 91.33% for cracks. This is significantly better than the performance of the benchmark methods, RFC, AdamBPANN, and Adam-DCNN. The newly developed CV-SSA-SVM method can be a valuable tool for pavement maintenance agencies to help them conduct periodic pavement condition surveys [22].

A technique for crack detection in pavements using digital image processing and the Matrix Laboratory programming language (MATLAB) was developed. The technique first captures an image of the pavement using a digital camera. Then, an image pre-processing operation is performed to remove environmental interference as much as possible. Finally, an image thresholding method is used to separate the pixels in the image into two groups: cracks and non-cracks. The thresholding value is determined by finding the point at which the two groups have equal numbers of pixels. The proposed technique was successfully able to detect and remove the presence of unwanted objects in images, even in difficult situations where the surface of the pavement is less visible. The technique was also shown to have a good processing time, which can be considered an indicator of the pavement crack parameters [23].

A simple, low-cost computer vision method for crack detection and classification uses the Hough transform to identify cracks in highly textured images. The results show that the proposed method is effective in labeling and classifying pavement cracks, with an accuracy of 92.14% for vertical cracks, 93.03% for diagonal cracks, and 95.61% for horizontal cracks [24].

3. Problem Statement and Objective of The Study

Traditional methods of distress detection and measurement were time-consuming, labor-intensive, and dangerous for the personnel involved.

This study performs image processing measurements to detect and measure flexible pavement distresses using image processing techniques.

The main objective of this study is to be quick, safe, and reduce the number of laborers required.

4. Steps Of The Study

4.1 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.

4.2 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:

4.2.1 Measurement of distresses lengths and widths

A. Cracks

Fig. 2. Longitudinal crack No.1.

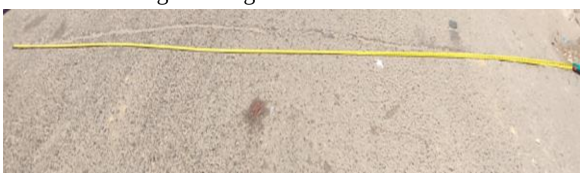

Fig. 3. Longitudinal crack No.2.

Fig. 4. Longitudinal crack No.3.

Fig. 5. Transverse crack No.4.

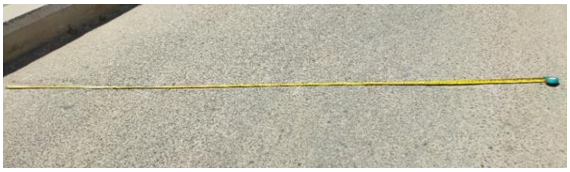

Fig. 6. Transverse crack No.5

Fig. 7. Transverse crack No.6.

Fig. 8. Transverse crack No.7.

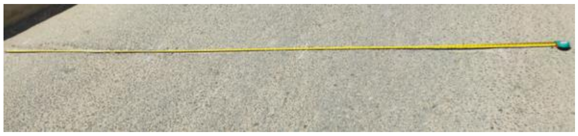

Fig. 9. Transverse crack No.8.

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.

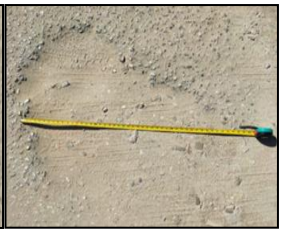

Fig. 11. Pothole No.2.

Table 2. Measurements of Potholes

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

4.2.2 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

4.3 Applying image processing programs to detect and measure pavement distresses

4.3.1 Detection of road distresses Using PCI geomatica program

"PCI Geomatica program" is not an abbreviation. It is the full name of the software suite. The software suite is called PCI Geomatica. It is a software suite for geospatial data processing and analysis. It is used for a variety of tasks, including image processing, GIS, and remote sensing. The detection of road distresses using the PCI Geomatica program is presented in the flowchart of Figure 16. The flowchart involved image preparation, image conversion, and feature extraction (detection) steps.

A. Image Preparation:

Convert image to PIX format

After inputting the image and loading the image, the image had to be converted to the PIX format (pixel format). The JPEG format image or other formats could not enable the researcher to extract any features from the normal image while using the PCI Geomatica program, so the image had to be converted to the pixel format.

Add channels

The raster image (pixel format) consists of three channels: red, green, and blue. The number of channels had to be increased so that features could be extracted in channels far from the main channels of the image. In this step, the researcher added new channels to the original image.

B. Image conversion:

Convert the image from raster to vector format.

C. Feature Extraction (Detection):

The black area and colored lines represent the shape of the distresses.

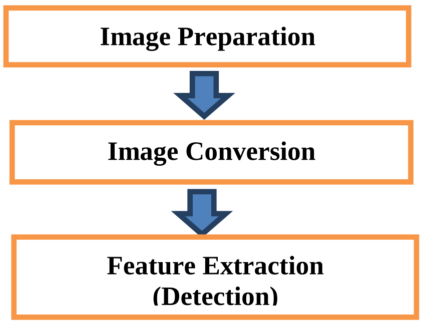

Fig. 16. The flowchart of the distresses detection process.

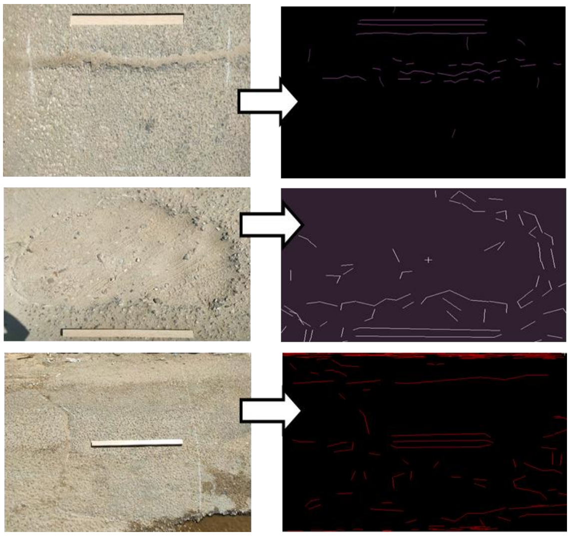

Fig. 17. Detection process of the distresses.

4.3.2 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.

4.3.2.1 Measurement of distresses lengths and widths

A. Cracks

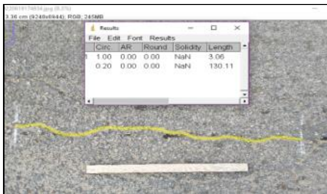

Fig. 18. Longitudinal crack No.1.

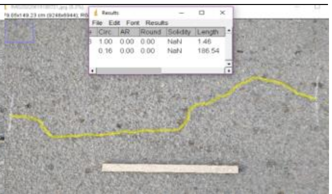

Fig. 19. Longitudinal crack No.2.

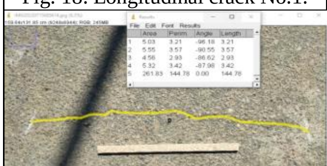

Fig. 20. Longitudinal crack No.3.

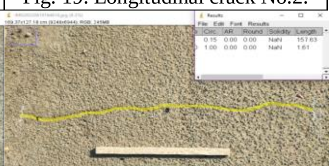

Fig. 21. Transverse crack No.4.

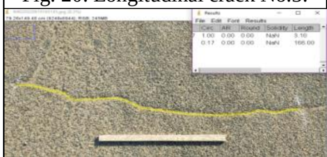

Fig. 22. Transverse crack No.5.

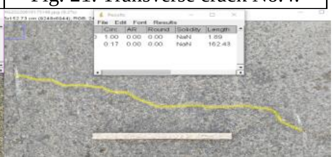

Fig. 23. Transverse crack No.6.

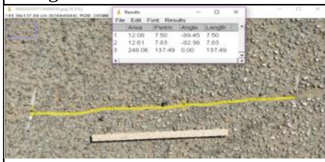

Fig. 24. Transverse crack No.7.

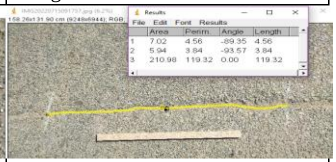

Fig. 25. Transverse crack No.8.

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

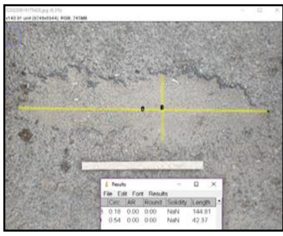

Fig. 26. Pothole No.1.

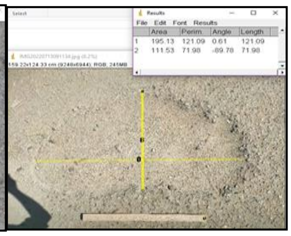

Fig. 27. Pothole No.2.

Table 6. Measurements of Potholes

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

4.3.2.2 Measurement of distresses areas

A. Depressions

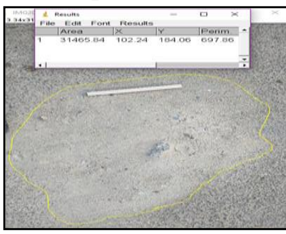

Fig. 28. Depression No.1.

Fig. 29. Depression No.2.

Table 7. Measurements of Depressions

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

B. Patching

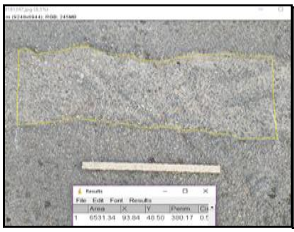

Fig. 30. Utility Patching No.1.

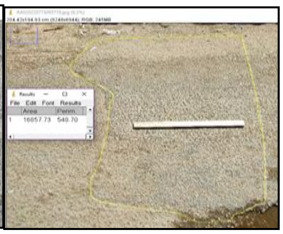

Fig. 31. Patching No.2.

Table 8. Measurements of Patching

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

5. Results and Discussion

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

5.1.1 Length of pavement distresses

The results showed that the length of distresses measured using the Image J program was greater than that measured by the manual measurement method. This is likely due to the fact that the Image J program is able to detect smaller and thinner distresses than the manual measurement method. The correlation of results obtained by using the Image J program with the manual measurement method showed a high correlation, as indicated by the high coefficient of determination R^2 = (0.9999). This means that there is a strong linear relationship between the two sets of results. In other words, the results obtained by using the Image J program were closely related to the results obtained by using the manual measurement method. Table 9 and Figure 32 provide more detailed information about the results. The table shows the length of distresses measured using the two 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 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 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 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 length of distresses in pavement images.

Table 9. The Comparison Results of the Length of pavement Distresses

Distress type	Manual measurements (m)	Measurements of image j program (m)
longitudinal crack No.1	9.70	9.95
longitudinal crack No.2	12.85	13.16
longitudinal crack No.3	1.39	1.45
transverse crack No.4	5.00	5.10
transverse crack No.5	9.25	9.46
transverse crack No.6	3.00	3.17
transverse crack No.7	4.56	4.71
transverse crack No.8	3.70	3.81
pothole No.1	1.40	1.45
pothole No.2	1.10	1.21
Regression model		y = 1.0191x + 0.053
R^2		0.9999

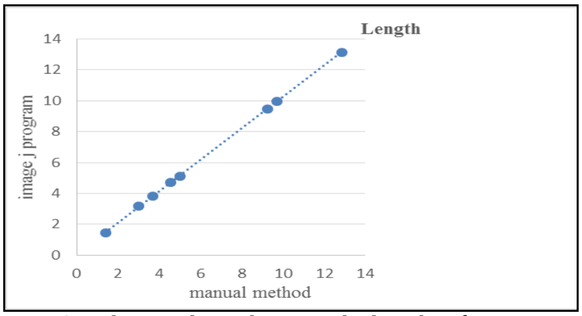

Fig. 32. The correlation between the lengths of pavement distresses measured using the manual method and the Image J program.

5.1.2 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. 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 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). This means that there is a strong linear relationship between the two sets of results. In other words, the results obtained by using the Image J program were closely related to the results obtained by using the manual measurement method. Table 10 and Figure 33 provide more detailed information about the results. The table shows the width of distresses measured using the two methods for the images in the dataset. The figure shows a scatter plot of the results, with the width of distresses measured using the Image J 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 10. The Comparison Results of the Width of pavement Distresses

Distress type	Manual measurements (cm)	Measurements of image j program (cm)
longitudinal crack No.1	3.03	2.98
longitudinal crack No.2	1.46	1.42
longitudinal crack No.3	4.00	3.28
transverse crack No.4	2.37	3.46
transverse crack No.5	2.43	2.70
transverse crack No.6	2.17	1.81
transverse crack No.7	7.75	7.10
transverse crack No.8	5.75	5.50
Regression model		y = 0.8586x + 0.4094
R^2		0.9257

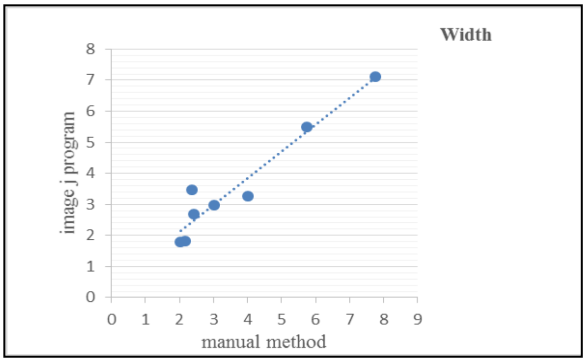

Fig. 33. The correlation between the widths of pavement distresses measured using the manual method and the Image J program.

5.1.3 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. 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 with the manual measurement method showed high correlation, as indicated by the high coefficient of determination R^2 = (0.9451). This means that there is a strong linear relationship between the two sets of results. In other words, the results obtained by using the Image J program were closely related to the results obtained by using the manual measurement method. Table 11 and Figure 34 provide more detailed information about the results. The table shows the area of distresses measured using the two methods for the images in the dataset. The figure shows a scatter plot of the results, with the area of distresses measured using the Image J 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 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 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 area of distresses in pavement images.

Table 11. The Comparison Results of the Area of pavement Distresses

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

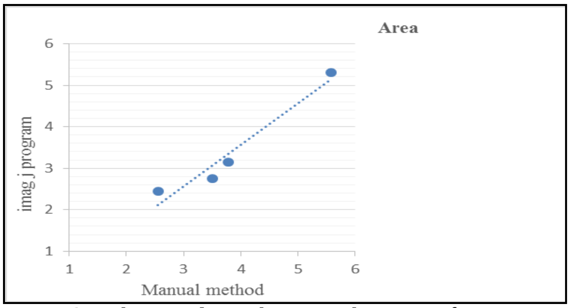

Fig. 34. The correlation between the areas of pavement distresses measured using the manual method and the Image J program.

5.2 Limitations of the Study

Manual method: The manual method is labor-intensive as requires at least three people to carry out measurements of pavement distresses, time-consuming, and not safe, as it exposes those who take the measurements to the risk of accidents on the road. It can be difficult to identify and measure all of the pavement distresses accurately using the manual method.

Image processing technique: The image processing technique can be affected by the quality of the images, the weather, and the lighting conditions.

Sample size of images: The study used a relatively small sample size of images. This may not be enough to accurately represent the different types of pavement distresses that occur in Egypt.

5.3 The Challenges Faced During the Study

- Measurement of pavement distresses during the passage of vehicles on the road.
- Getting human experts to manually identify and measure the pavement distresses accurately.
- Overcoming the challenges of weather and lighting conditions.
- Identifying the correct distress type from the images. This was because some of the distress types were very similar to each other.
- Obtaining a permit from the police to carry out measurements at the area of study.

5.4 The Shortcomings of the study

- The study does not cover all pavement distresses.
- One image covers a small area, and therefore pavement distresses of long lengths and large areas need more than one image.
- The results may not be accurate for all human experts.

6. Conclusion

1. Image processing techniques are used to detect and measure road distresses using the PCI Geomatica program and the ImageJ program.
2. Feature extraction is used by the PCI Geomatica program to determine the location of road distresses in images. The correctness of the distresses can also be verified using the PCI Geomatica program.
3. The Image J program is used to measure the length, width, and area of road distresses in pavement images.
4. The image j program is a fast image-processing program, requires some experience, and is free.
5. The results of the study showed that the measurements obtained using image processing techniques were similar to those obtained using the traditional method with high coefficients of determination R^2 = (0.9999, 0.9257, and 0.9451) for length, width, and area respectively.

7. Recommendations

1. Further studies are needed using image processing techniques to detect and measure road distresses.
2. The government should permit 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. It’s recommended to encourage field application and evaluation to evaluate the performance of image

processing techniques.

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.

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