Application of Image Processing to Measure Road Distresses

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Abstract: - Pavements usually experience different types of distresses due to repeated traffic loads, aggressive environmental conditions, construction materials, soil condition of the underline subgrade, and the method of construction. Longitudinal and transverse cracking, potholes, rutting, and bleeding are common examples of such distresses associated with flexible pavements. As time progresses, the severity of these distresses increases and consequently, ride quality is adversely affected. Early detection and measurement of the extent of distresses coupled with prompt reactive measures are necessary to keep the pavement function at an acceptable level. Traditional methods for distress detection and measurement are laborious, time consuming, and subject the involved personnel to accidents. In contrast, image measurement methods are effortless, safe, and can be performed in a short time. This research paper performs image processing measurements to estimate areas of a pothole and alligator cracking, and sets a program for plane measurements of an area that experience rutting. The image measurements are compared with the traditional measurements. The results show that image measurements are close to those obtained by using the traditional methods.

Key-Words: - Pavement surface cracking, road distresses, alligator cracking, rutting, image measurements.

1. Introduction

One of the main transportation systems in the Kingdom of Saudi Arabia is the highway system, which is developing in a rapid manner. The main function of this system is to connect cities, towns and villages throughout the kingdom. Therefore, it is required to have highways in an excellent condition from both structural, and functional point of views. The Strategic Highway Research Program (SHRP) and the Ministry of Transportation in Saudi Arabia (MOT) include the identification of these distresses [1-2].

Highways usually experience different types of distresses caused by high wheel contact stresses, repeated traffic loads, material properties, methods of construction, and climatic changes. Distresses that affect flexible pavements include; longitudinal and transverse cracking, patching and potholes, surface defects, and rutting. If these distresses are left without treatment, the ride quality and safety of the motorists will be degraded. Moreover, failed pavements require costly maintenance and repair which in turn cause restrictions in traffic flow, and consequently results in undesirable traffic congestion. Therefore, to keep these highways safe and durable, prompt maintenance should be carried out [3, 4].

Detection and measurement of pavement distresses is necessary for keeping a well maintained highway network. It enables highway authorities to initiate prompt measures while distresses are in their early stages. The earlier distresses are fixed, the cheaper it is to maintain the highways.

This work is devoted to facilitate the measurements of different highway distresses such as longitudinal cracks, potholes, and rutting. Different images for some common distresses that affect flexible pavements on Makkah highways in the Western Province of the Kingdom of Saudi Arabia were captured. These images were taken by a Nikon digital camera with a resolution of 5.2 mega pixels. Image processing technique based on image measurement analysis is utilized to automate the measurements of various road distresses. Measurement experiments are applied using ImageJ software to estimate area of pothole, and crack length and width, plane measurement of an area affected by rutting for different highway distresses areas on Makkah city highways [5, 6].

2. Automation of Pavement Distresses Data Collection

Some of the work related to the digital image measurement techniques in surveying highways is presented.

The digital highway data vehicle (DHDV) is a project conducted at the University of Arkansas. It implemented a real-time automated survey system for pavement surface cracking survey [7-8]. The project focused on the data analysis portion of a new automated system capable of collecting and analyzing pavement surface distress, mainly cracks, in real time through the use of a; efficient image processing algorithms; and multicomputer, multi-CPU-based parallel computing. Three protocols of producing distress indices incorporated into the automated system were examined: the AASHTO interim distress protocol, the World Bank's Universal Cracking Indicator (CI), and the Texas Department of Transportation's method. The results concluded that the automated system were consistent for multiple passes of the same pavement sections. Wang in mentioned that the researchers faced tremendous tasks in optimizing imaging algorithms to speed up the processing at the same time without sacrificing accuracy in identifying and classifying cracks. The work introduces and summarizes the experiences in developing parallel algorithms in image processing used in a real-time system. The hardware system for processing images is based on the ubiquitous multiple Central Processing Unit (CPU) x86 platform that has the capability of two levels of parallel processing at multiple CPU level and within each CPU level. The results of survey with the DHDV and the distress analyzer on a network of about 161 km (100 mil) of pavements are also presented. In addition, a manual survey was conducted on the same network of pavements. CI is used because the distress analyzer is fully automated and results of the analysis are provided in synch with image collection, the potential cost savings when compared with manual survey methods and other semi-automated survey technologies are significant [8].

Lazic describes the road condition data collection process in Saskatchewan and how obtained information is used to derive an effective maintenance strategy [9],. This strategy begins by obtaining adequate information about the road network being analyzed so that the right decisions can be made at the right time. Saskatchewan Highways and Transportation (SHT) collects different road condition data either by using automated data collection system or by manually rating the road network. SHT has equipped its data collection van with equipment that provides for the automated data collection at highway speeds. Road distresses are collected annually to describe conditions on thin membrane surface, granular and asphalt concrete pavements. They included international roughness index, cracking, rutting, surface condition and depressed transverse cracking. Structural indicator is also calculated to provide information about the structural capacity under the traffic loading demand. In addition to the automated data collection process, the SHT preservation staff also manually rate the gravel surface roads by collecting protruding rock, surface gravel and stability data. The SHT automated data collection system consists of the longitudinal profiling subsystem, transverse profiling subsystem and digital video distress collection subsystem. The collected road condition data are then post processed and stored in the centralized database to be later analyzed in the SHT Asset Management System (AMS) that is concerned with optimizing available funding and providing most benefits for the entire road network.

Marz presented objective guidelines for performance assessment of digital imaging systems [10]. Digital imaging systems installed in automated highway evaluation vehicles are generally designed on a modular basis where system components produced by various manufacturers are assembled to customize the system and fulfill the users' needs at minimum cost. In most of such cases, manufacturers' specifications for a given system component would not be reliable with respect to the eventual performance of that system component. On the other hand, no guidelines are available for performance assessment of imaging systems as assemblies of discrete components. As such, even the refinement of optics, software, and other electronic accessories is traditionally performed based on trial and error. The assessment process can be accomplished through measurement of well-defined properties of images. This is achieved by standard and reliable methods then by applying the above evaluation criteria to the imaging systems of the Florida Department of Transportation's pavement evaluation vehicle. The assessment results will enable the highway personnel involved in image interpretation to better understand the properties that define the quality of images, systematically assess the capabilities and limitations of imaging systems and help formulate rational standards for specifying imaging needs. To enhance the development of accurate automatic image evaluation software, this will need clear-cut criteria that can identify the spatial and tonal limitations of imaging systems.

The L.C.P.C is a French public laboratory who has in charge the research and development of new methods for the conception, construction, preservation and repair of roads and bridges. The management of pavement maintenance was the most important task assigned to this laboratory. The L.C.P.C wishes to automate and speed-up the process of surveying road pavements with detection and characterization of road surface distresses. For this purpose, Meignen et al. developed a system which analyzes sequences of video images to discover among them possible pavements distresses [11]. The researcher studied the application of neural networks to detect road distresses from video sequences. The design uses one NN to analyze each image extracted from a video sequence, followed by a more simple NN which analyzes each time only a small part of each image using a pre-processor scanning. Finally, preferred to simplify the role of the NN by putting a head one image pre-processing sequence to extract objects identified later by the NN. They describe the sequence of treatments that used and detail each processing step; improvement of the original image, extraction of possible distresses and identification of theses distresses by the NN. They concluded that the NN can be used to identify distresses on a video sequence of pavement images. They conclude that the Neural Networks can be used to identify distresses on a video sequence of pavement images. Clustering the pixels as an object seems to be a good way to improve the identification of distresses and to reduce noise. The test give good rates of identification with a reasonable learning times.

Kil et al. [12] present an algorithm for road distresses classification and identification using a combination of hierarchical classifier and expert systems – sub image and object processing for preventive road maintenance before cracks and potholes become too severe, leading to economic benefits. The algorithm will substitute for the current approach of using human operators to categorize road distresses that is both labor intensive and time consuming. They describe a two step algorithm that automates road distresses identification with high accuracy. Data analysis shows that overall system performance at the object level as: P_D of 0.9, probability of correct distress identification of 0.96, and P_{FA} of 0.79 false objects per image frame. In contrast, different classifiers have been used by Shandiz et al. [13] to identify road surface cracks in digital images. Region Growing Classifier (RGC) method is used to divide all surface road images into two main groups. The group covering alligator and block cracks is classified using Wavelet Statistic Feature Classifier (WSFC), vertical and horizontal histogram and proximity. The second group covers longitudinal, transverse cracks and other kind of distress which is classified using histogram, RGC and proximity classifiers. Multi Layer Perceptron MLP neural network is also used to judge about the cracks. Bayesian network classifiers are used in an application to remote sensing image classification to classify road cracks [14].

Chhadar et al. [15] present a new algorithm based on wavelet transforms for automated segmentation of the pavement condition data. Denoising scheme to remove random noise caused by the collection device and random extreme distress in the pavement while essentially preserving the important information followed by a singularity detection based segmentation algorithm was used. During segmentation stage, singularities of the smoothed waveform are detected, and they are marked as isolated singularities or border points. Isolated singularities are suppressed and the remaining singularities are used as border information to segment the pavement condition data into regions that exhibit similar characteristics. The proposed approach follows the envelope of the original pavement data.

Rutting which develops under the wheel paths as a result of permanent deformation in any of the pavement layers or the subgrade is a type of a distress that affects flexible pavements. It is generally caused by the consolidation or lateral movement of the materials due to the cumulative axle loads over the life of the pavement. (Banks, J., H., 2004; Yoder, E., J., et. el., 1975; Huang, Y., H., 1993) [16, 17, 18].. Among the different automated methods to measure rutting is the Laser Profilometer. It consists of an aluminum beam that is placed over the test section, resting on legs on either side of the test section. A measuring head moves along the beam and takes readings every 10 mm for a total length of 2.56 meters. Transverse profiles of the test section are taken at several test points along the section. From these profiles the average rut depth and other factors relating to the permanent deformation of the section can be determined. The ROMDAS Transverse Profile Logger (TPL) uses ultrasonic technology to measure the distance from the TPL to the pavement. It is mounted on the front of a vehicle. The collected data is used to construct the transverse profile of the pavement which is processed to get the rut depth (Kandhal, P.P., et. el, 2003; McGhee, K., 2003; Bennett, C. R., 2002) [19-21].

3. Methodology

The proposed imaging method is applied to measure the dimensions of road distresses such as crack length, width and area. To supplement the imaging technique for the sake of comparison, manual measurements of length and width in case of longitudinal, transverse cracks, patching, potholes, and rutted area are performed using a tape, ruler and vernier caliper after making some marks on the distressed area. The images are taken for these distresses including the necessary road marks and in the presence of a unit of known length such as a metal ruler. The digital camera images are analyzed and some extracted images are chosen to demonstrate and compare manual and imaging measurements. The ImageJ software is image processing software written by NIH Image [5-6]. ImageJ for Windows XP has been used in this research. The system is available at no charge and provides a good environment for developers in displaying images, analyzing and enhancing images, designing and applying filters, geometric and mathematical operations, measurements such as mean and standard deviation. The ImageJ can be customized via a plug-in java classes. These classes may contain a sequence of calls or routines that ImageJ interprets and executes. Some of the most important ImageJ features are listed in Table 1.

4. Results and Discussions

The following sections present measurement results of road distresses.

Table 1 Some of the main features of ImageJ Software.

Feature	Description
Supports stacks	Possible to process a series of images that share a single window.
Multithreaded	Time-consuming operations can be performed in parallel with other operations.
Measurement	Calculates area, distances, angle, and pixel value statistics for user defined selections.
Open architecture	Provides extensibility via Java plugins. User-written plugins can be developed using ImageJ's editor and Java compiler. This makes it possible to solve image processing problems.
Spatial Calibration	Provides real world dimensional measurements in units such as millimeters.
Availability	Available free in the public domain

4.1 Measurement of an alligator cracking

Fig.1 shows a severe alligator cracking. It is desired to estimate the area that is affected. First, a spline curve is fitted to a set of points that are lying around the region of the alligator cracking. Before running the measurements, the scale must be set. This can be done by calling "Set Scale" to set the scale as shown in Fig.2; the scale is equal to 2 pixels/cm.

Fig.1. Digital measurement of an alligator cracking.

The image measurement results are shown in Fig.3. This is close to the manual results for the area of the alligator cracking of 6 m^2.

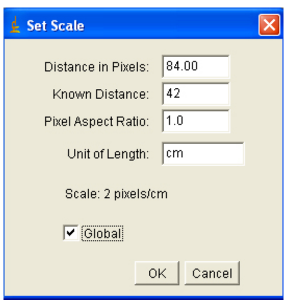


Fig.2. ImageJ window to set the scale of measurement.

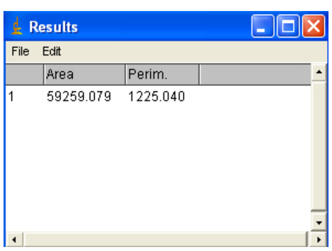
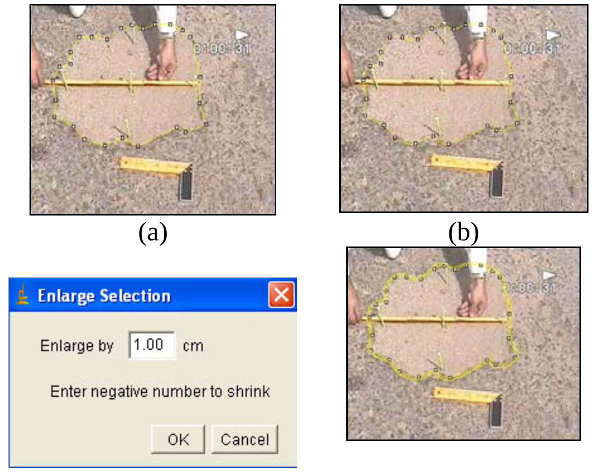


Fig.3. Measurement results for the alligator cracking.

4.2 Measurement of a pothole

This section presents the necessary steps to measure the area of a pothole. It introduces the application of curve fitting to specified points at the border of a pothole. Figure 4 shows the application of fitting a spline curve to a set of points that are lying on the border of a polygon. Fig. 4 (d) demonstrates the possibility of enlarging the whole curve fitted by a desired length.



(a) (b) (c) (d)

Fig.4. (a) Fitting a set of polygon border points. (b) Fitting spline curve between points in (a). (c) Selection window to enlarge the curve in (b) by 1 cm. (d) Final enlarged area.

4.3 Measurement of rutting

A section of a highway with severe rutting was selected for this part of the study. It is located on the Makkah Madinah Highway in the northern part of the city of Makkah. It is about 5 kilometers north of Saydah AAiesha Mosque. The section was carefully selected among other locations, the selection that was based on safety consideration as well as on the extent of rutting the section has. Although, the section has an extensive amount of rutting, but the amount of traffic that uses the section is light that permitted closing the lane under study. This helped conducting the field data collection with ease and comfort compared to the other candidates that have heavy traffic which makes lane closure of the lane under study impractical. Figure 5 shows a photograph of the selected site with the points marked on the pavement.

Fig.5. Photograph of the points in the studied area

After the site was selected, the site was prepared to conduct the field data collection. Three sections were selected and each one was marked with ten almost equally spaced points. The distance between the sections was about 0.4 m and the distance between the points in each section was about 0.3 m. This distribution of points in each section covered the whole studied lane. The three sections, the point distribution and the actual distances are illustrated in Figure 6. The data collection was planned to fulfill the requirements to determine the elevation of the points using the traditional method as illustrated in Figure 7. The usage of image processing is intended to be used to measure the rut depth in a future research.

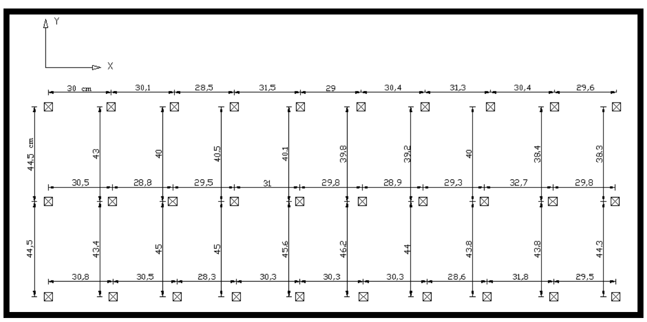


Fig.6. Distribution of the points in the studied area

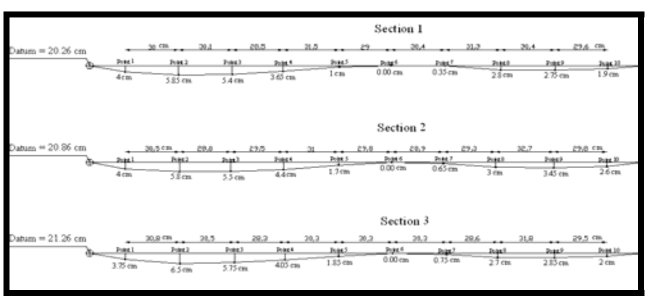


Fig. 7. Rut measurement using the traditional method

5. Conclusions

This research paper demonstrates the applicability and benefits gained by using image processing to measure highway distresses. It shows that the technique is effortless, safe, and can be performed in a short time. This technique can substitute the traditional road measurements, which are tedious, time consuming, and subject the involved personnel to accidents. The application of image measurements is applied to different highway distresses using ImageJ software. The dimensions of the distressed area such as length and width in case of longitudinal, transverse cracks, and potholes were digitally and manually measured. The images were captured, using a digital camera with 5.2 mega pixels resolution. The measurements for these distresses were carried out with the help of highway marks and in the presence of a unit of known length (a metal ruler). The results show that image measurements are reasonably close to those measured by manual methods. Moreover, this investigation shows that image measurement can be applied to different disciplines within the field of civil engineering.

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