IDEA

Innovations Deserving Exploratory Analysis Programs

Highway IDEA Program

Automated Real-Time Pavement Crack Detection and Classification System

Final Report for Highway IDEA Project 106

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1. Introduction

Statistics published by the Federal Highway Administration indicate that the maintenance and rehabilitation of highway pavement in the United States requires over 17 billion dollars per year. Currently, maintenance and repairs account for nearly one-third of all federal, state and local government road expenditures [1]. In the present manual systems, road crews walk along a given road with a vehicle following behind [2]. When the crew finds cracks, they stop the vehicle and measure the cracks.

While pavement monitoring and evaluation are essential requirements for effective pavement management, the manual systems described above are slow, costly, unsafe and subjective. Ideally, an automated crack detection system should detect all types of cracking and other surface distress of all sizes and at any collection speed. It should be affordable, easy to operate, and capable of daylight operation [3]. Pavement management systems should provide meaningful, repeatable distress ratings to sections of pavement, thus supplying critical information for maintenance-related decision making. Much effort has been paid to the development of automated pavement crack detection algorithms and systems [1-13].

Our research group has collaborated with the engineers of UDOT to implement a real-time pavement crack detection and classification system including conducting field tests. In this report we will discuss the experiments, and evaluate the performance of the system using the five descriptive statistics (accuracy, sensitivity, specificity, positive predictive value, and negative predictive value) that are the most commonly used objective indices to evaluate the performance of classification results in clinical practice. We will also compare our system with other pavement crack detection systems discussed in published articles, materials, and related websites in the public domain.

2. The Developed System

The outside view of the system is shown in Fig. 1.

Fig. 1. The outside view of the system

Currently, the resolution required by UDOT is 2mm which can be accomplished by using one camera with a wide angle lens. The experiments indicate that distortion does not affect classification accuracy. The camera is mounted at the end of a boom on the top of the van. The monitor and computer are installed in the van, as shown in Fig. 2. We developed the software to make the system easy for the operators. The system used DMI to control the camera shutter speed and to synchronize it with the vehicle speed.

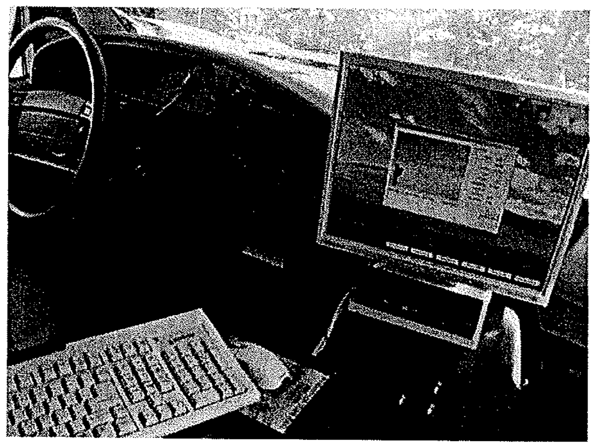


Fig. 2. The inside view of the system

3. Field Tests and Performance Analysis

Our research group at Utah State University and UDOT engineers conducted field tests to evaluate and validate the performance of the system. To test the maximum processing speed of the system, we drove the vehicle for about 70 miles with the average speed >70 mph, and occasionally >80mph. The system works very well under all situations, i.e., traveling at these speeds, the system can perform real-time processing, and is very reliable and robust. The developed system can survey an entire road without sampling. We have surveyed a 75-mile segment of highway I-15 in an hour, and got satisfactory results. We also conducted field test on about 1-mile of selected road (932 images) to compute the accuracy, sensitivity, specificity, positive predictive value, and negative predictive value of the system.

Given a true-positive (TP), the number of correctly classified cracks, a true-negative (TN), the number of correctly classified non-cracks, and a false-positive (FP), the number of incorrectly classified cracks, and a false-negative (FN), the number of incorrectly classified non-cracks, the five objective indices are defined as follows:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

$$Sensitivity = \frac{TP}{TP + FN} \quad (2)$$

$$Specificity = \frac{TN}{TN + FP} \quad (3)$$

$$Positive\ predictive\ value\ \ (PPV) = \frac{TP}{TP + FP} \quad (4)$$

$$Negative\ predictive\ value\ (NPV) = \frac{TN}{TN + FN} \quad (5)$$

The reliability and validity of an automated system can be tied directly to these five indices. The higher the five indices are, the more reliable and valid the system is. Index values indicate and validate system performance from different aspects, and can evaluate the system much better than accuracy evaluation alone. If only using accuracy as the criterion, a system with high accuracy may have high false positive rate. Such indices are commonly used for medical practice and for evaluating CAD (computer aided diagnosis) systems. For the collected pavement images, we obtained the results as shown in Table 1. A detailed list of the test images and results can be downloaded from **http://cvprip.cs.usu.edu/idea**. More field tests will be conducted with further financial support later.

Table 1. The Analysis of the Results

Runs	TE	TP	FP	TN	FN	
1	2	95	0	5	0	
2	5	100	0	2	0	
3	3	97	1	4	0	
4	4	96	0	5	0	
5	5	91	0	7	2	
6	4	96	0	5	0	
7	1	98	0	6	1	
8	1	98	1	6	2	
9	1	104	0	5	0	
total	26	875	2	45	5	
		Accuracy	99.24487594			
		Sensitivity	99.43181818			
		Specificity	95.74468085			
		PPV	99.77194983			
		NPV	90			
		Type error rate	2.804746494			

The values show that the system's performance is very good. The accuracy rate is greater than 99%. Since in the selected segment of the road there are very few images having no cracks, the NPV is 90%; otherwise (which would be the norm), it would be higher than 95%. Some errors are of the type in which the cracks have been detected, but, their classification result is different, such as a combined crack is classified as transversal or vice versa, or similar categorization cases. However, some of these cases cannot be consistently correctly classified by human experts. Thus, we feel that new standards for crack classification should be established. For example, some problematic examples are shown in Figure 3.

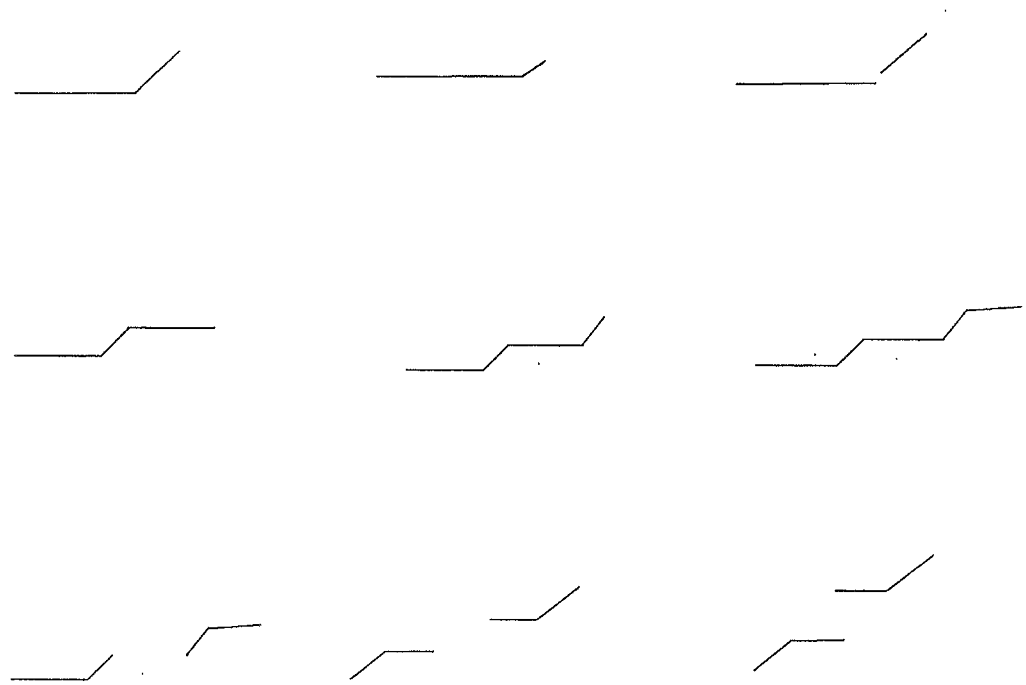
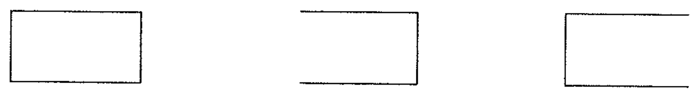


Fig. 3. Problematic crack configurations in the transverse direction

How should these examples be categorized? The examples in Fig. 3 really illustrate the need to standardize classification criterion. There are so many different criteria from different users to classify the above examples. Similar situations exist along the longitudinal, and both diagonal directions. In the real world, many more problematic cases exist. This is a problem not only for real-time automated processing systems, but also for off-line automated processing system and human experts. There are many different manuals for crack detection and classification from the Federal, States, and organizations. The establishment of a more useful automated crack classification criterion/standard should be a subject for further study.

Other issues may arise in the equipment/vehicle operation. An operator should attempt to drive the vehicle in the center of the lane; otherwise, classification errors will be generated and the wheel-path information will be inaccurate. For instance, Fig. 4(a) is an alligator crack. However, if the operator drives to the right, the image will be collected as Fig. 4(b), and he if drives to the left, the image will be collected as Fig. 4(c). Both cracks will be classified as combination cracks, and the wheel-path information will be affected. Therefore, in order to achieve the best survey results, the operator should try to keep the vehicle in the center of the lane.
Here, we just indicate the requirement for image collection. Fig. 4(b) and (c) will cause problems for post-processing (machine or human) as well as real-time processing. The

operator of the vehicle should try to keep in the middle of the road, especially, for finding the cracks in the wheel-path.



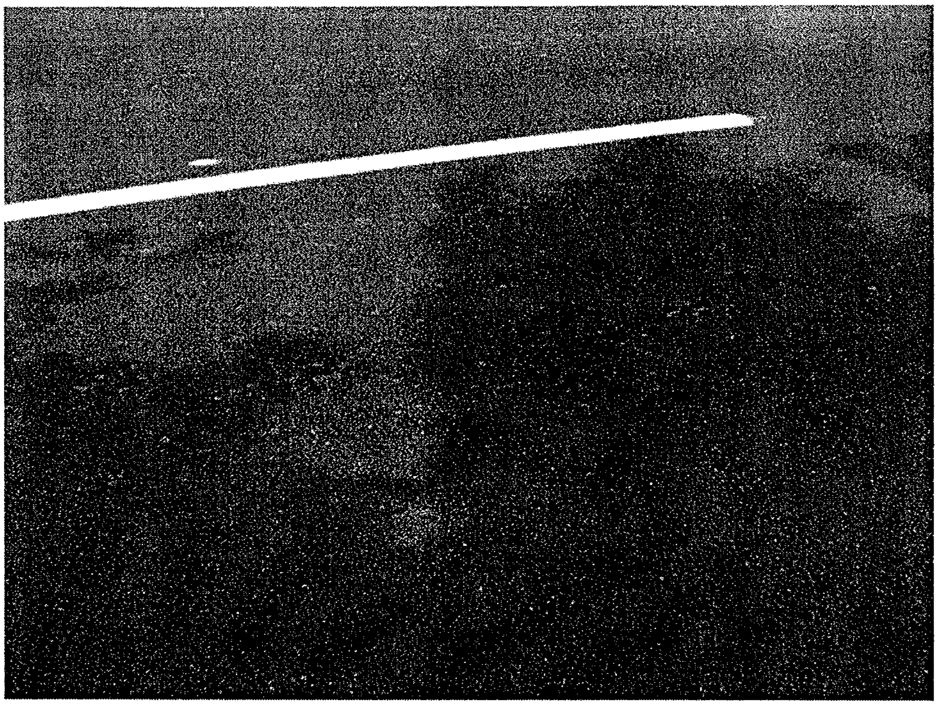
(a) (b) (c)

Fig. 4. The influence of the driving path

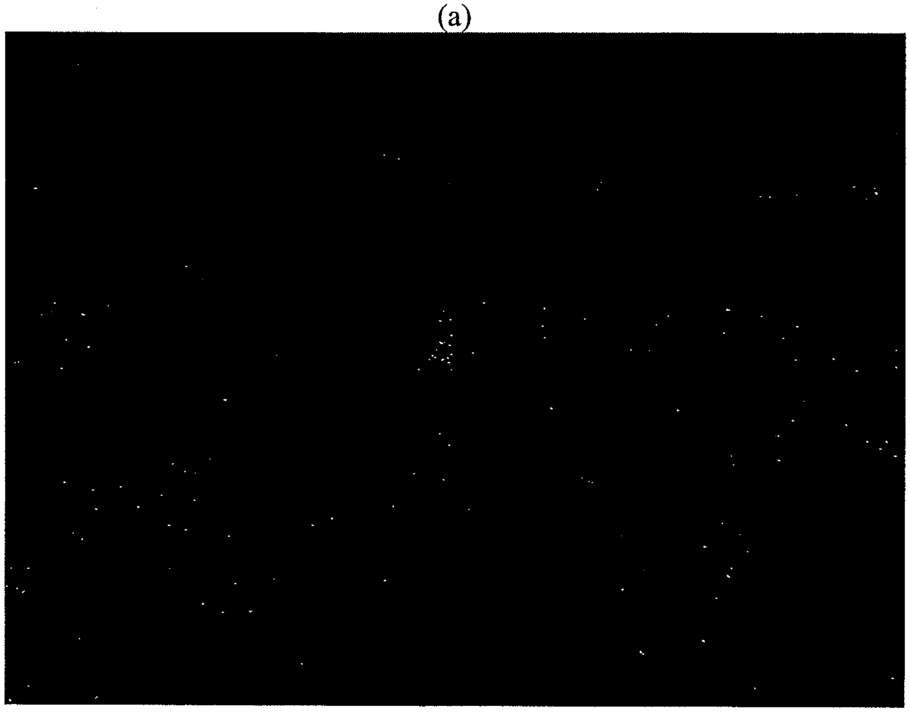
Our system can process shadows and noise in the images as well. Figure 5(a) shows an image with shadows and a white line, and 5(b) is the same image after processing by our system. The small noise spots will have no effect on the classification since they will be eliminated by thresholding. Our system's processing result on Fig. 5(a) is "NO CRACK". Fig. 6 is another example, Figure 6(a) has two white lines, and the top of the image is brighter than the bottom part. Figure 6(b) is the image after processing, and the final result of our system is "NO CRACK".

Fig. 7 is yet another example. 7(a) is the original image having many lines including a joint. 7(b) is the result of our system. After removing the joint (which is a straight line and has smooth boundaries) and thresholding, the final processing result of our system is "NO CRACK".

The algorithm can handle noise spots, noisy lines, etc. Also, it can remove the joint lines required by the users.

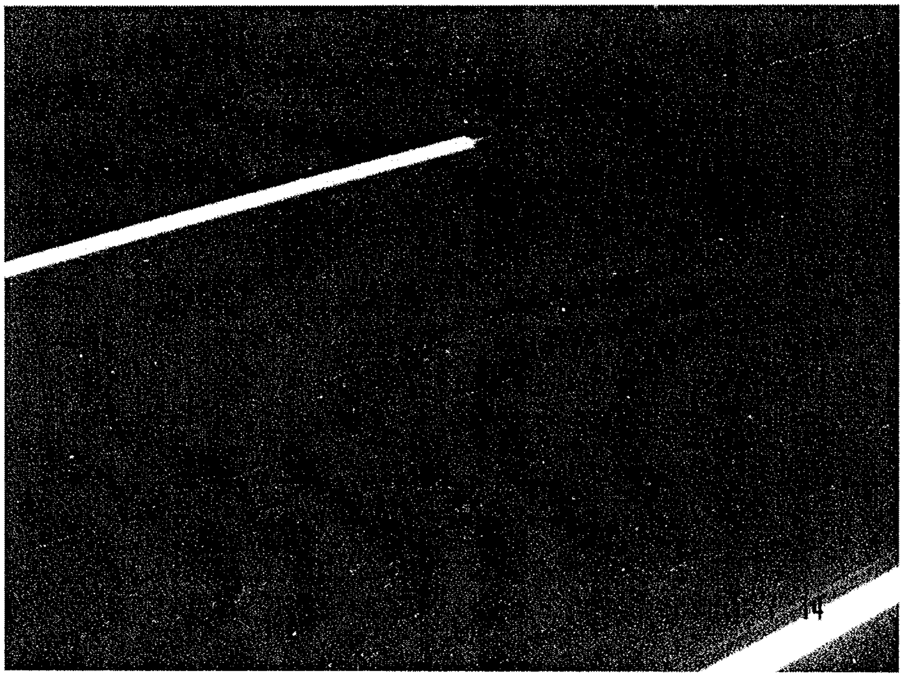


(a)

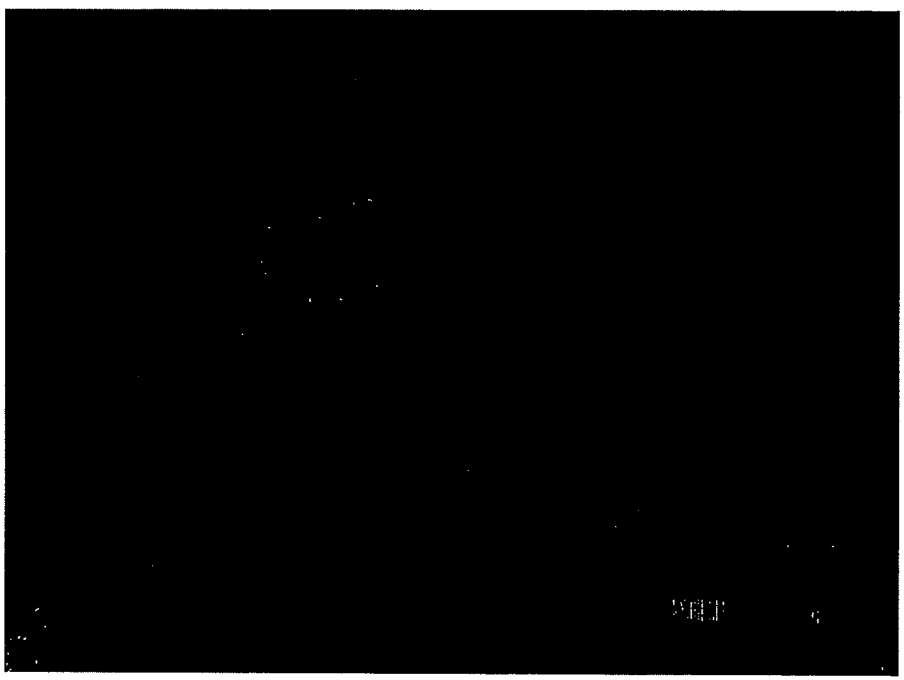


(b)

Figure 5. (a) Image having shadows and a white line, (b) Processing result by our system

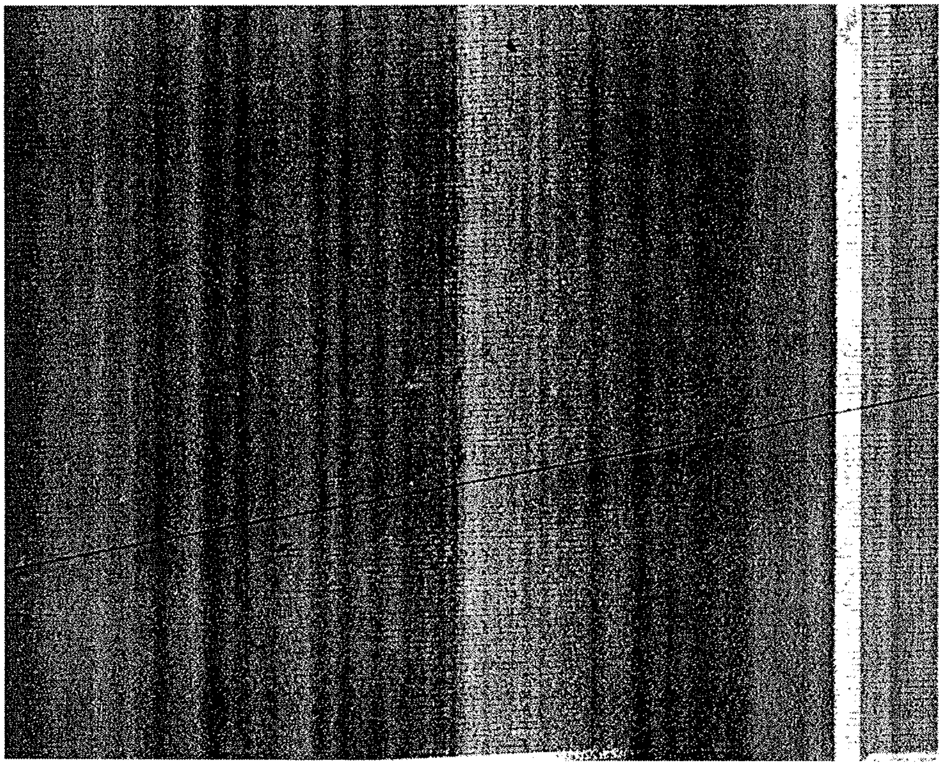


(a)

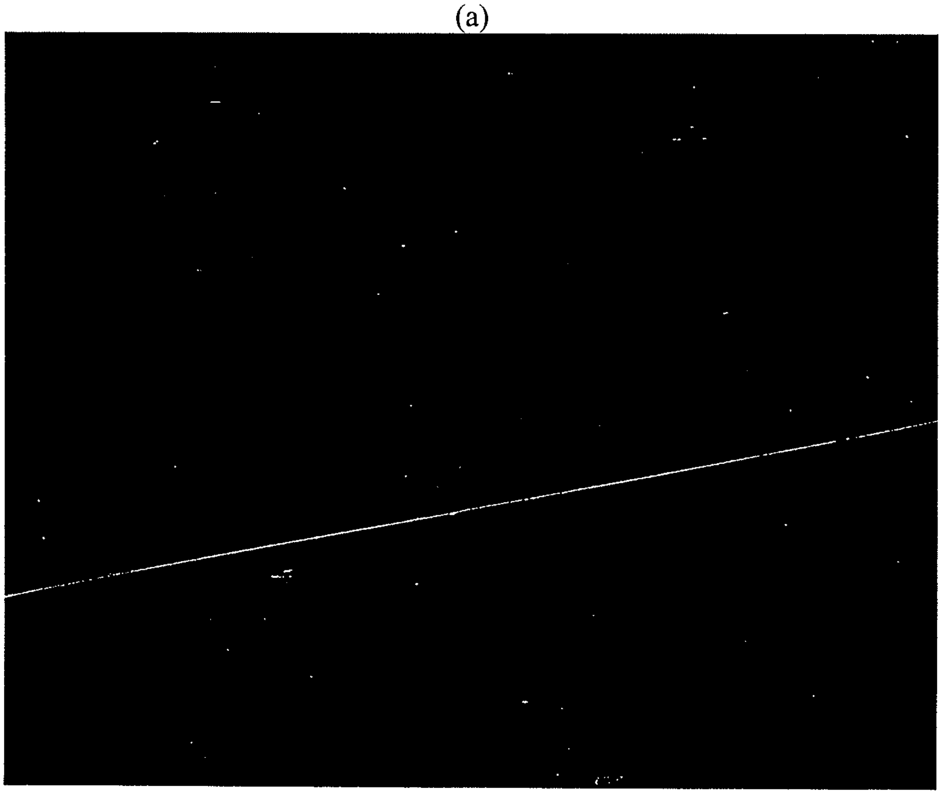


(b)

Figure 6. (a) Original image, (b) Processing result by our system



(a)



(b)

Figure 7(a) Original image, (b) Processing result by our system

4. Comparison of Automated Pavement Crack Detection and Classification Systems

A real-time pavement crack detection and classification system should perform the analysis in real-time, and the corresponding result should be stored in the pavement management database for later evaluation and comparison to pavement history and other facilities.

An ideal automated crack detection system should detect all types of cracks at any collection speed. It should be affordable, easy to operate, fast and accurate.

Problems associated with existing automated crack detection systems and methods are as follows:

1. They require special devices (special lights, lasers, etc.) that increase cost and limit the application of the system or method;
2. They suffer from very low processing speeds and accuracy;
3. They deal only with certain distresses categories; if other distress categories are required, the complexity of the system increases dramatically or the system cannot handle the additional processing;
4. They cannot achieve real-time processing; most systems only perform real-time recording (on film or videotape) and then perform offline processing and analysis.
5. They can only measure severity qualitatively.

The following are three pavement distress/crack detection and classification systems. WiseCrax, PicCrack, and Pavement Cracking Detection System developed by the CVPRIP (Computer Vision, Pattern Recognition and Image Processing) Laboratory, Utah State University. The system developed by the CVPRIP Lab is not commercially available, but the prototype has been established.

Table 2 describes a brief comparison of the detection methods, speeds, and accuracies of the above mentioned systems.

Table 2. Comparison of Pavement Management Systems

Crack Detection System	Affiliation	Crack Detection Method	Crack Detection Speed	Crack Detection Accuracy	Discussion
WiseCrax/ NT [2, 13]	Roadware Inc.	WiseCrax/NT processes the pavement image video tapes from the ARAN system. It will automatically detect cracks (length, width, area, orientation), classify them according to type, severity and extent and generate summary statistics and crack maps.	Pavement image video recording speed 13~90 km/h Offline process and human intervention	WiseCrax processed over 92% of the video with greater than 85% accuracy. For the Peel Region project, where WiseCrax cannot maintain 80-85% accuracy, video rating and/or manual review will be substituted.	It can perform in three modes: automatic, interactive, or fully manual.
PicCrack [14, 15]	Samsung Inc.	The main image analysis methods[15] are: - Edge Detection - Binarization - Morphology - Hough Transform	6mph on-line process, Offline process and Human intervention	Extremely high FPs and FNs rate and the result is not in an intuitive format. Only part of the job is done automatically, most of tasks have to be done manually.	There are 3 subsystems in their system: data collection subsystem, pavement image and distress analysis subsystem, PMS. All the crack detection/analysis is done offline. All the road related information is entered manually [14, 15].
Automated Real-time Crack Detection and Manage-ment System[3, 4, 6, 8,9]	CVPRIP (Computer Vision, Pattern Recognition and Image Processing) Laboratory, USU	Advanced computer vision, pattern recognition , image processing and artificial intelligence techniques[3, 4, 6, 8,9].	Up to 85mph	>97% Fully automated. No human intervention is needed.	Real-time pavement data collection, and real-time pavement crack detection and analysis.

5. Conclusions

Conventional visual and manual pavement distress analysis techniques are very costly, time-consuming, dangerous, labor-intensive, tedious, and subjective, have a high degree of variability, are unable to provide meaningful quantitative information, and almost always leading to inconsistencies in distress detail over space and across evaluations. Automated pavement crack detection and management has been studied for more than two decades. We have developed automated real-time crack detection and classification system, have conducted field tests, and actual data collection, and used five descriptive statistics (accuracy, sensitivity, specificity, positive predictive value, and negative predictive value) to objectively evaluate the performance of the system. The results demonstrate that the system is very accurate, robust, effective, and can process images in real-time. The system is ready for surveying pavement distress on roads and highways.

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