A Comparative Study on Automated Pavement Crack Detection and Classification Systems

H. D. Cheng[1], Liming Hu[1], Xiangjun Shi[1], C. Glazier[2], G. Kuhl[2]
[1]Dept. of Computer Science, Utah State University, Logan, UT 84322-4205
[2]Utah Department of Transportation, Salt Lake City, UT 84119

Abstract
Pavement crack detection and analysis is an important component of pavement management systems. Conventional visual and manual pavement crack 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 lead to inconsistencies in distress detail over space and across evaluations. The automated detection of pavement cracks on roads requires special attention from the transportation authorities in every state of the U.S. and other countries relying on surface transportation. Many articles have been published and several pavement crack detection systems are developed. In this study, we will compare some pavement crack detection systems based on from published articles and materials in public domain, and related websites. It will help the researchers to develop better improved systems.

Keywords: Automated Pavement Crack Detection, Pavement Management System, Neural Network, Fuzzy Logic

1. Introduction
Statistics published by the Federal Highway Administration indicate that the maintenance and rehabilitation of highway pavements in the United States requires over 17 billion dollars a year. Currently, maintenance and repairs account for nearly one-third of all federal, state and local government road expenditures [1].
Pavement crack detection and analysis is an important component of pavement management systems. Conventional visual and manual pavement crack 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 lead to inconsistencies in distress detail over space and across evaluations [3, 4, 8]. Fig. 1 shows a typical approach to do manual pavement survey. The workers are walking on the road and a vehicle follows them [2].
Pavement monitoring and evaluation are essential requirements for effective pavement management. An automated crack detection system should ideally 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, providing critical information for maintenance-related decision making. A lot of efforts have been paid to the automated pavement crack detection algorithms and systems [1-13].

2. 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 analysis. Fig. 2 is the schematic diagram of the real time pavement crack detection and classification system.
An idea automated crack detection system should detect all types of cracking, and other surface distress, of all size and at any collection speed. It should be affordable, easy to operate, and capable of daylight operation. Pavement management programs would be very adequately served by devices which give meaningful, repeatable distress ratings to sections of pavement, providing the critical information for maintenance decisions [1-3, 12].
Problems with some automated crack detection systems and methods are as follows [3]:

1) They require special devices (special lights, lasers, etc.) that would increase cost and limit the application of the system or method;
2) Some systems have very low processing speed and low accuracy;
3) They can deal only with certain kinds of distresses; if there is a need to deal with more kinds of distresses, the complexity of the

system would greatly increase or it could not handle the additional work;

4) They cannot achieve real-time processing; some systems only can do real-time recording (on film or videotape) and then perform offline processing and analysis.
5) The severity can only be measured qualitatively.

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

2.1. WiseCrax/NT (Roadware Inc.)

WiseCrax/NT processes the pavement image video tapes from the ARAN (Automatic Road Analyzer). It will automatically detect cracks (length, width, area, orientation), classify them according to type, severity and extent and generate summary statistics and crack maps. The NT system features a simplified user and enhanced detection and classification algorithms. It can perform in three modes: automatic, interactive, or fully manual.

The problems with the Roadware system [2, 13].

The crack detection is done offline. Operators use light pen to follow the cracks on the screen. If the crack is thin, only one stroke is needed, and the severity is graded as low. If it needs two strokes to cover the width of the crack, the severity is graded as moderate. If it needs 3 strokes or more, the severity is graded as high. There is no quantitative measure of the severity.

Special lighting: Strobe lighting. This will increase the cost of the system.

Visual verification. It requires human intervention, therefore, the cost is high and human error will be introduced.

Combined picture problem: the pictures are combined and artifacts are generated. It may produce too many false positives (FPs).

2.2. PicCrack (Samsung Inc.)

Piccrack is Samsung's pavement crack detection system it which similar to Roadware's WiseCrax/NT crack detection system [14, 15]. It also processes the pavement images offline, which are collected by the data collection subsystem. It can automatically measure pavement crack type, extent, and severity [15].

Main problems with the Samsung pavement system [15]:

All of the segment related information is entered manually. It is labor intensive and very costly. The segment name, from location, to location, length etc. are all entered manually.

The image data is also linked to the segment manually. It is labor intensive and costly.

Substantially high error rate, and the result is not in an intuitive format. There are too many FPs (False Positives) and FNs (False Negatives). In Fig. 5, the positions tagged with crosses should be cracks, but the actual cracks are the dark areas.

i. The Crack detection is done offline. Operators have to correct the huge amount of FPs and FNs manually. It is labor intensive and costly. Also human errors could be introduced.
ii. Extremely low vehicle speed (<6mph), and, certainly, it cannot be done in real-time.
iii. The severity is only measured qualitatively.

2.3. Automated Real-Time Pavement Crack Detection and Classification System

The main characteristics of the automated real-time pavement crack detection system by CVPRIP Lab of USU are:

i. All the segment related information is handled automatically.
ii. The image data is linked to the segment automatically.
iii. High accuracy rate (>97%) and the result is in an intuitive format.
iv. The pavement image data acquisition and the pavement crack detection are done in real-time. Vehicle can travel as high as 85mph. No need to store images that would require a huge amount of storage of the computer.
v. All types (longitudinal, transversal, diagonal, alligator, combined) of cracks can be detected automatically and accurately.
vi. The severity will be measured quantitatively and qualitatively based on the users' choice.

Table 1 describes a brief comparison of the detection methods, speeds, and accuracies of the above mentioned systems.

3. 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. In this paper, we have compared several pavement crack detection and classification systems based on the materials available to the public. Due to the limitation of the resource of the information, we certainly could not and did not include all of the algorithms and systems, and would like to update it in the future when more information is available. The major criteria for comparison should include: accuracy, speed, cost and operation easiness, etc. We hope this will help researchers, engineers and scientists to develop and design more efficient and effective algorithms and systems for automated real-time pavement crack detection and management.

Reference

[1] S. Tsao, et al., "Image-based expert-system approach to distress detection on CRC pavement", *Journal of Transportation Engineering*, Vol.20, No. 1, pp.52-64, 1994.

[2] RoadWare, WiseCrax/NT *Introduction Video*. 1997.

[3] H.D. Cheng, et al., "Automated real-time pavement distress analysis", *Transportation Research Record*, No. 1655, pp. 55-64, 1999.

[4] H.D. Cheng, et al., "Novel approach to pavement cracking detection based on neural network", *Transportation Research Record*, No.1764, pp.119-127, 2001.

[5] R.Ferguson, D. Pratt, and I. Macintyre, "Automated detection and classification of cracking in road pavements (Roadcrack)", *Road and Transport Research*, Vol. 8, No.2, pp. 39-47, 1999.

[6] H.D. Cheng, et al., "Novel approach to pavement cracking detection based on fuzzy set theory", *Journal of Computing in Civil Engineering*, Vol.13, No.4, pp. 270-280, 1999.

[7] R.Ferguson, D. Pratt, and I. Macintyre, "Automated detection and classification of cracking in road pavements (RoadCrack)", *in Proceedings of the 1998 19th ARRB Conference*, 1998.

[8] H.D. Cheng, and M. Miyojim, "Novel system for automatic pavement distress detection", *Journal of Computing in Civil Engineering*, Vol.12, No.3, pp.145-152, 1998.

[9] H.D. Cheng, and M. Miyojim, "Synthesized images for pavement management system design", *Journal of Computing in Civil Engineering*, Vol.10, No.1, pp. 60-66, 1996.

[10] A. Mastandrea, B. Swindall, and G. Klassen, "Development and implementation of an automated facility inventory system", *Transportation Research Record*, No.1500, pp. 127-133, 1995.

[11] H. Lee, and H. Oshima, "New crack-imaging procedure using spatial autocorrelation function", *Journal of Transportation Engineering*, Vol.120, No.2, pp. 206-228, 1994.

[12] H.N. Koutsopoulos, "Improved methods for classification of pavement distress images", *Transportation Research Part C: Emerging Technologies*, Vol. 2, No.1, pp. 19-33, 1994.

[13] RoadWare, Online WiseCrax Product. introduction, *http://www.roadware.com/*.

[14] Samsung, Pavement Management System, *http://www.visionnet.co.kr/*.

[15] Samsung, PicCrack User's Guide: Salt Lake City.

Figure 1 Manual Survey [2]

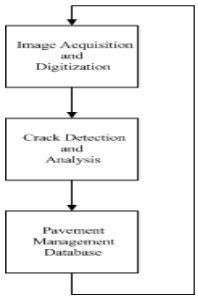

Figure 2 Schematic diagram of automated real-time pavement crack detection and management system

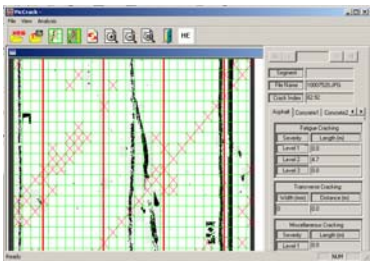

Figure 3 PicCrack detection result [14, 15]

Table 1 Comparison of pavement management systems

Crack Detection System	Affiliation	Crack Detection Method	Crack Detection Speed	Crack Detection Accuracy	Memo
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 Recogni-tion 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.