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基于高精度3D道路路面数据的路面裂缝测量评价方法

Protocol Based Pavement Cracking Measurement with High-resolution 3D Pavement Surface Model

汪雯娟／著

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ECONOMY & MANAGEMENT PUBLISHING HOUSE

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Contents

Chapter 1 Introduction

1.1 Background

Pavement cracking is one of the most concerned pavement surface defects which affect pavement ride quality, safety, and structural health of the pavement system performance (Haas et al., 1994). Since the American Association of State Highway Officials (AASHO) Road Test initiated in the late 1950s, cracking condition has been monitored on a regular basis and recognized as a prime indicator of pavement deterioration (HRB, 1962; Haas et al., 1994; Huang, 2001; Miller and Bellinger, 2003). Multiple reasons such as excessive loading, dynamic environmental condition, and material aging could lead to pavement cracking. Severe cracking may significantly deteriorate the overall pavement condition, degrade the roadway serviceability, and even jeopardize the entire pavement structure. In modern pavement management, it is recognized that proper and timely countermeasures should be conducted to prevent cracking from further propagation and resulting in more severe damages. Therefore, monitoring field cracking condition becomes a routine task for highway agencies.

Cracking characterization is a complex process which demands many aspects of expertise and efforts. Since 1980s, automated pavement cracking data collection and analysishas progressively become a mainstream. Generally, this process contains pavement image collection, cracking detection, classification, quantification, reporting and so on. To capture the characteristics of cracking, a number of guidelines and standards have been released by different organizations. However, many constraints such as technology limitation and funding shortage have compromised the mature application of automated pavement cracking collection. The consistency, repeatability, and reliability of automated cracking measurement has remained unsatisfactory for decades. Recently, a breakthrough in pavement data collection was made possible through the emerging 3D vision technology. The PaveVision3D Ultra system is capable of acquiring 1 mm resolution 3D pavement surface data at highway speed (60 mph or 100 kmh). Meanwhile, the new AASHTO cracking protocols are released to support fully automated cracking characterization. With the advance of data collection technology and the updated protocols, the state of the practice needs to be addressed in a more reasonable manner.

1.2 Problems and Objectives

Among various pavement distresses such as rutting and faulting, cracking always has been the center of attention in pavement design and management. This dissertation attempts to use the emerging technology, the 1 mm 3D virtual pavement surface model, to improve the current practice of cracking measurement. The intention of this research is to provide insights for pavement engineers so that the most advanced data sets can be effectively and efficiently applied for accurate cracking measurement, characterization and eventually cracking-orientated decision making.

Specifically, the following problems have hindered the rapid progress of cracking measurement practice:

- Automated cracking data collection and measurement has been inaccurate and unreliable for decades.
- Procedures for automated cracking data analysis are inconsistent among a variety of protocols.
- The characterization of cracking suffers from lack of a uniform and practical standard. For example, the classification of cracking width which is used to determine the cracking severity level varies significantly across different protocols, some of which are even controversial.

- The quantification of cracking has been a vague concept in most of the existing protocols. The length and width defined in these protocols are ambiguous and may lead to different measuring results. Technical rigor is demanded in cracking quantification.
- There lacks an integrated system for comprehensive cracking evaluation. It is difficult for the users to efficiently utilize the detailed cracking data for a wide range of pavement management purposes.

To resolve the above-listed problems, the following research objectives are implemented in this book:

- To review the state of the practice of cracking measurement.
- To identify the existing issues in cracking measurement.
- To introduce the state of the art in cracking data collection.
- To evaluate the new AASHTO cracking protocols by identifying their advantages and weaknesses.
- To design a sophisticated algorithm which is able to automatically extract the lane region from the full frame pavement images in a robust manner.
- To implement the new AASHTO PP 67-10 & PP 68-10 based cracking measurement:
    - To define and propose a methodology for cracking blob extraction.
    - To establish a generalized methodology for cracking length measurement.
    - To propose a simplified method for average cracking width measurement.
    - To develop a set of methodology to classify different types of cracking.
- To propose and compare two advanced methods for accurate cracking width identification:
    - To propose an orthogonal projection method for continuous cracking width measurement.
    - To propose a Laplace's equation method for continuous cracking width measurement.
    - To comparatively study the features of the two methods.
    - To compare the measuring results generated by the two methods.

    - To explore potential applications of cracking width distribution.
- To develop a comprehensive system for cracking evaluation:
    - To establish a multi-layer cracking evaluation system based on protocols PP 67-10 & PP 68-10.
    - To elicit a set of fuzzy theory based membership functions for each cracking attribute.
    - To define a set of rules to aggregate a comprehensive cracking index.
    - To perform a case study demonstrating the effectiveness of the system with a field data set.

1.3 Overall Organization

The organization and overall framework of this dissertation study are shown in Figure 1.1. This chapter is an introduction section and outlines the background, problems and objectives, and overall structure of this book.

The main purpose of Chapter 2 is to conduct a thorough literature review for this study. In Chapter 2, definition and mechanisms of pavement cracking are reviewed. The methods for cracking data collection and analysis are summarized. Cracking rating and cracking information based decision making are also discussed.

Chapter 3 aims at introducing the new AASHTO protocol PP 67-10 & PP 68-10. The instrument represents the state of the art in pavement data collection: the PaveVision3D Ultra system is introduced. In addition, the lane identification algorithms are developed in this chapter.

Chapter 4 develops a set of mathematical methods for implementing PP 67-10 based cracking characterization. Based on field data, techniques for cracking blob extraction, quantification, and classification are developed.

Chapter 5 proposes two advanced and computationally intensive methods for continuous cracking width calculation. Both methods aim to resolve the controversial practice in cracking width measurement and improve the accuracy. Features of the two methods are comparatively studied. Results from the two methods and their applications are then discussed, respectively.

Chapter 6 proposes a multi-layer system for comprehensive cracking evaluation. With the reporting items derived based on previous chapters, the framework of this system, fuzzy membership functions, and score aggregations are elaborated in this chapter. A case study is also conducted to demonstrate the application of the system.

Chapter 7 concludes this book. Recommendations for future studies are also presented.

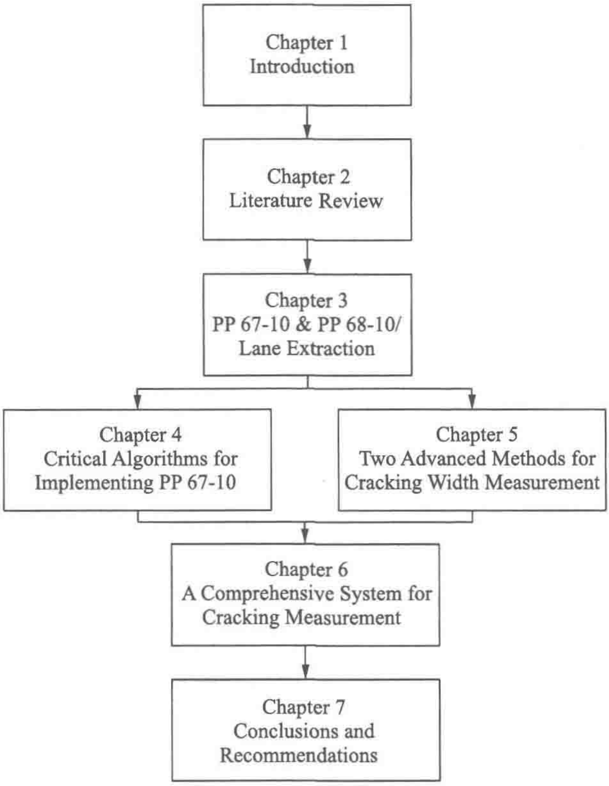


Figure 1. 1 Overall Layout of This Book

Chapter 2 Literature Review

2.1 General

Under traffic loading and environmental effect, many distresses such as cracking, potholes and rutting occur in pavements, among which cracking is on top of pavement engineers' concern list (Miller and Bellinger, 2003). Field cracking data collection and post cracking processing are significant tasks in pavement evaluation. To understand the problem, a comprehensive literature review was conducted which covers background, past and current practices, the most advanced technology, and other relevant studies. This literature review is organized in this order: First, fundamentals of pavement cracking and cracking measurement are briefed. Second, the evolution of cracking data collection technology is reviewed and summarized. Third, the state of the art in cracking detection and mapping is introduced. The protocols for cracking quantification and classification are compared and analyzed. With such protocols, the roles of cracking information in comprehensive pavement evaluation systems are discussed. Finally, a summary is presented.

2.2 Fundamentals of Pavement Cracking

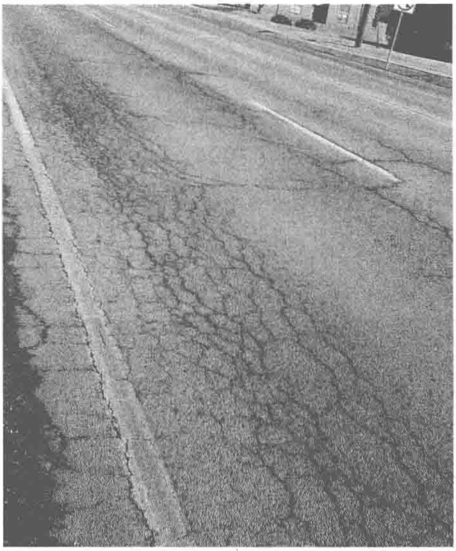
2.2.1 Definition and Causes

Cracking is the fissure appearing on the pavement surface due to material fatigue, repeated loading, construction defects, climate gradient or a combination thereof (ASTM, 2009). It is one of the most significant pavement distresses adversely affecting driving maneuver ability and ride quality and a major indicator for diagnosing deterioration for all types of pavements (Paterson, 1994; Lee and Kim, 2005). Figure 2.1 is a Right of Way image showing a real world pavement section exhibiting cracking on its surface.

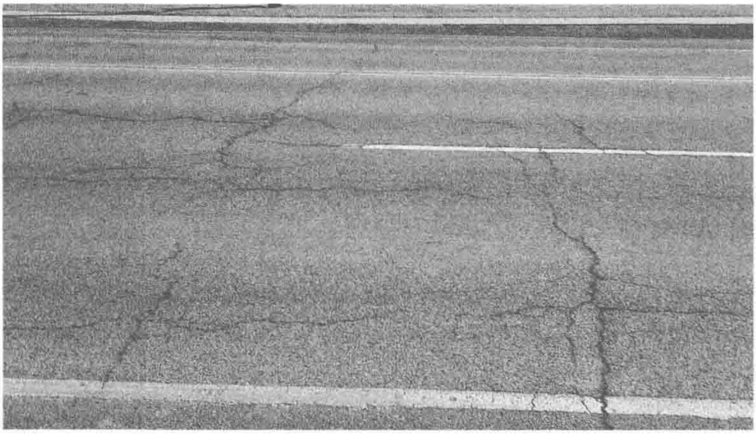
Figure 2.1 Pavement Surface Exhibiting Cracking

Source: Image taken by PaveVision3D Ultra on 03/03/2013 on Arkansas Highway 100 Eastbound.

Generally, cracking is categorized into non-load associated (thermal) cracking and load associated cracking. Non-load associated cracks are primarily due to the contraction and shrinkage of the surface layer, reflection from underlying pavement joints, poorly constructed paving joints, daily temperature cycling or subgrade settlement, as an example shown in Figure 2.2a (Miller and Bellinger, 2003; ASTM, 2009). Load associated cracking usually exhibits when the wheel loads exceed the design capacity of the pavement. Such cracking is usually on the wheel-path of the pavement lanes, as shown in Figure 2.2b (Miller and Bellinger, 2003; ASTM, 2009).



a. A Typical Fatigue Cracking
Source: Image Taken on 02/26/2015 at Perkins Rd., Stillwater, OK.



b. A Typical Non-load-Associated Cracking
Source: Image Taken on 02/26/2015 at Perkins Rd., Stillwater, OK.

Figure 2. 2 Examples of Two Types of Pavement Cracking

2. 2. 2 Fundamentals in Cracking Characterization

Accurate cracking survey is necessary so that timely interventions and proper countermeasures could be applied to prevent cracking from leading to further damage. However, cracking propagation is a complicated process and the physical properties of the cracking (i. e. , formation and propagation) have not been fully understood under the current body of knowledge. Thus, engineers analyze cracking through geometric and visual characteristics. Conventionally, the major ones include type, intensity, extent, severity, and relative location (Paterson, 1994). These aspects are to some degree related to the mechanism of the cracking formation, prediction of propagation, and subsequent maintenance and repair actions (Paterson, 1994; PIARC, 2012). Cracking type characterizes the visual pattern or orientation of the cracks; sometimes a cracking is named by type, such as longitudinal, transverse and alligator cracking. Extent reflects the quantity of the cracking; some of the measures are total length, extended area, and percentage of the surface and so on. Severity usually refers to the rupture width observed from the pavement surface. Also, in some occasions the material damages such as spalling and faulting on cracks are considered in determining the cracking severity level. Relative location indicates the location of cracking along the transverse direction, normally distinguished by within and without the wheel-path. In modern pavement management, cracking data are collected based on the above four fundamentals.

2.3 Technology for Cracking Data Collection

The earliest cracking measurement can be traced back to the 1950s, when the AASHO Road Test was conducted (HRB, 1962). Over the past half century, three phases of cracking data collection have been undergone: manual inspection, 2D image, and 3D image. The evolution of data collection methods is graphically summarized in Figure 2.3.

Early pavement survey has been mainly conducted by human observers through visual examination. Different detail levels of information can be acquired through different methods such as walking and windshield survey (Paterson and Scullion, 1990). To be more representative and scientific, different sampling methods have been developed based on statistical principles for visual survey (ASTM, 2009). Although the most renowned Long-Term Pavement Performance (LTPP) program has manually collected pavement condition data in the United States and 15 other countries for more than two decades, manual survey is recognized as the least preferred approach for pavement data collection. It is extremely labor-intensive, prone to errors, and dangerous to the raters (Wang, 2000).

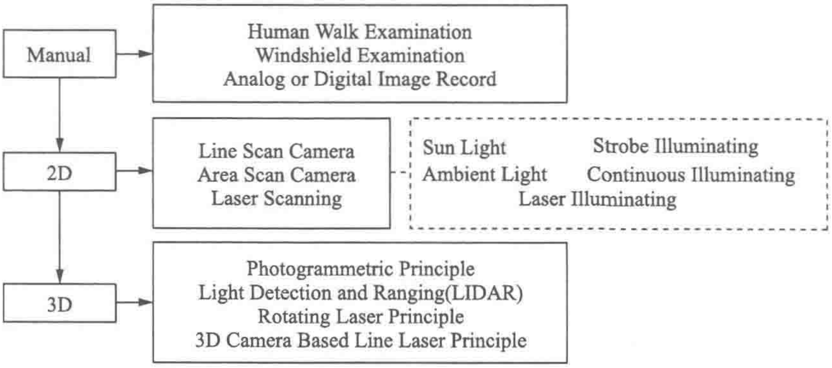


Figure 2. 3 Evolution of Image Based Pavement Condition Data Collection

In the mid-1980s, with the advance of computer and sensing technology, automated image collection gradually emerged. However, not until the mid-1990s, when automated survey data reached an acceptable accuracy level and the survey equipment became affordable and available to the normal users, had the automated systems been rapidly widespread and recognized as the most effective and reliable approach in cracking data collection. As shown in Figure 2. 4, a typical automated pavement condition survey vehicle is equipped with cameras for shooting continuous images. Data acquisition, storage, display, and processing subsystems are the essential components of the system, as illustrated in Figure 2. 5 (Wang, 2000).

For more than a decade, the 2D image collection system has been the dominated automated device used by highway agencies. The principle of 2D systems is to shoot the grayscale pavement surface images for cracking analysis. Several generations of techniques have been used on 2D-based data collection systems. Specifically, the continuous improvement of lighting conditions is critical to eliminating the errors and improving reliability. However, research indicates that relatively poor visibility is shown on 2D systems when the pavement surface has complex textures (Wang, 2011). With the increasing needs for higher accuracy and precision, and the continuous and rapid development in sensor and optics technology, 3D technology based systems for pavement image