

EVALUATION OF CRACKS AND DISINTEGRATIONS USING CLOSE-RANGE  
DIGITAL PHOTOGRAMMETRY AND IMAGE PROCESSING TECHNIQUE

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Dedicated to Jesus Christ,  
My personal Lord and Savior,  
And  
To my beloved parents and family.

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## ABSTRACT

Serviceability of road pavements is continuously deteriorating due to traffic loading and poor qualities of the sub grade, sub base, base, or wearing course. To keep road pavements in good condition, maintenance and repair strategies must be based on an informed knowledge of current pavement condition. Such data are gathered by human inspectors who walk or drive along the road to assess the distresses and writing report sheets manually. This visual survey method which takes too much time and effort is too costly and compromises the safety of the field personnel. With an automated digital image processing technique of pavement distress analysis, more areas can be surveyed and the collected data can be analysed quickly. Furthermore, the automated method can improve the objectivity, accuracy, and consistency of distress survey data. This research is aimed at the development of an Automated Pavement Imaging Program (APIP) for evaluating pavement distress condition. The digital image processing program enables longitudinal, transverse, and alligator cracking to be classified. Subsequently, the program will automatically estimate the crack intensity which can be used for rating pavement distress severity. Advancement in digital photogrammetric technology creates an opportunity to overcome some problems associated with the manual methods. It can provide a low-cost, near real time geometrical imaging through digital photogrammetry without physically touching the surface being measured. Moreover, digital photogrammetry workstation (DPW) is user-friendly, less tedious and enables surface conditions to be represented as ortho-image, overlay contour with ortho-image, as well as digital elevation model. Results obtained by this technique are compared with the *Jabatan Kerja Raya* manual using conventional method to check accuracy. The algorithms developed in this study are capable of identifying type of cracking and its severity level at the accuracy about 90%. The combination of photogrammetric system and APIP has been shown to be capable of producing a similar accuracy to the existing system.

## ABSTRAK

Kebolehhormatan pavemen jalan merosot secara berterusan akibat pembebanan lalu lintas dan kualiti sub gred, sub tapak, tapak dan lapisan haus yang rendah. Untuk memastikan pavemen jalan berada dalam keadaan yang baik, penyelenggaraan dan strategi pembaikpulihan perlu diwujudkan berdasarkan maklumat terkini tentang keadaan pavemen. Data ini dikumpul oleh pemeriksa yang berjalan atau memandu di sepanjang jalan untuk menilai dan mencatatkan kerosakan di atas helaian laporan secara manual. Kaedah pengukuran secara visual yang mengambil masa dan usaha yang banyak ini memerlukan perbelanjaan yang tinggi dan mengancam keselamatan pemeriksa. Dengan menggunakan teknik pemprosesan imej digital automatik, lebih banyak kawasan yang mengalami kerosakan jalan dapat diperiksa dan dianalisis dengan cepat. Tambahan lagi, kaedah automatik boleh meningkatkan objektiviti, ketepatan dan kekonsistenan data yang diperiksa. Matlamat kajian ini adalah untuk membangunkan satu *Automated Pavement Imaging Program* (APIP) untuk menilai keadaan kerosakan pavemen. Program pemprosesan imej digital ini membenarkan retak memanjang, melintang dan aligator dikenalpasti. Berikutnya, program ini akan menganggar densiti keretakan bagi menilai tahap kerosakan pavemen secara automatik. Kemajuan dalam teknologi fotogrametri digital membuka ruang untuk mengatasi masalah-masalah dalam kaedah manual. Ianya dapat memberikan gambaran imej secara geometri pada kos yang rendah dan mendekati masa sebenar melalui fotogrametri digital tanpa menyentuh permukaan sebenar yang diukur. Tambahan lagi, terminal komputer fotogrametri berdigit (DPW) adalah mudah untuk digunakan, membolehkan keadaan permukaan digambarkan dalam imej-orto, kontor dan model dongakan digital. Kejituan keputusan yang diperolehi dengan teknik ini dibandingkan dengan hasil pengukuran manual yang dibuat berdasarkan buku panduan Jabatan Kerja Raya. Algoritma yang dibina dalam kajian ini berupaya untuk mengenalpasti jenis keretakan dan tahap kerosakannya pada kejituan 90%. Kombinasi sistem fotogrametri dan APIP telah menunjukkan keupayaan untuk menghasilkan ketepatan yang sama seperti sistem yang wujud.

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## LIST OF SYMBOLS

A, P	-	Object space point
$A$	-	Area
AASHTO	-	American Association of state highway and transportation officials
AC	-	Asphalt concrete
APIP	-	Automated pavement imaging program
ARAN	-	Automatic road analyzer
ASGLX	-	Average summed gray level value in the x-arrays
ASGLY	-	Average summed gray level value in the y-arrays
$b$	-	Base line
CCD	-	Charged couple device
CD	-	Crack density
CW	-	Crack width
$d$	-	Depth
$D$	-	Diameter
DEM	-	Digital elevation model
DLT	-	Direct linear transformation
DPW	-	Digital photogrammetry workstation
DTM	-	Digital terrain model
EDM	-	Electronic distance measurement device
$f$	-	Focal length
$\bar{G}$	-	Mean gray level
G	-	Gray level

GCP	-	Ground control point
GIS	-	Geographical information system
IBGL	-	Intermediate background gray level
JKR	-	Jabatan kerja raya
$l$	-	Crack length
LCD	-	Liquid crystal display
LTPP	-	Long term pavement performance
MM	-	Mathematical morphology
O	-	Perspective center point
Out	-	Output of gray scale intensity
$p$	-	Parallax
PMT	-	Photomultiplier tube
$r$	-	Element of the rotation matrix
RMS	-	Root mean square
RST	-	Road surface test
$S, SD, \sigma$	-	Standard deviation
SHRP	-	Strategic highway research program
SLR	-	Single lens reflex
$Th$	-	Optimal threshold level
$V$	-	Volume
$w$	-	Weight
WASHO	-	Western association of state highway officials
$\pi$	-	Pi
$\lambda$	-	Scale factor
$\omega, \phi, \kappa$	-	Rotation angles
$\mu$	-	Mean
$\alpha$	-	A significant level
$\gamma$	-	Density
$H_a$	-	Alternative hypothesis
$H_o$	-	Null hypothesis
$t_\alpha$	-	t statistic value

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## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Introduction**

Pavement distresses are visible imperfections on the surface of pavements. They are symptoms of the deterioration of pavement structures. According to Yoder (1964) pavement distress can be classified into two different types of failures. They are structural failure and functional failure. “A structural failure includes a collapse of the pavement structure or a breakdown of one or more of the pavement components of such magnitude to make the pavement incapable of sustaining the loads imposed upon its surface”. “Functional failure may or may not be accompanied by structural failure. However the pavement will not carry out its intended function without causing discomfort to passengers or without causing high stress in the plane or vehicle that passes over it, due to its roughness.”

The evaluation of pavement condition is an important part in pavement management. Accurate evaluations would result in a better chance that resources will be distributed normally. Thus, yielding a better service condition (Kim, 1998). Pavement

can be evaluated through the different types of distress experienced, such as cracking, disintegration and surface deformation. At present, there are various methods of conducting distress surveys, recording and analysing distress survey data. For examples, pavement engineers have long recognized the importance of distress information in quantifying the quality of pavements. This information has been used to document present pavement condition, chart past performance history, and predict future pavement performance.

## **1.2 Problem Statement**

Manual visual inspection of pavement surface condition is costly and time consuming. In many cases, work has to be done along fast moving traffic. Such condition would endanger the safety of the personnel involved. In the wake of tedious manual measurements and safety issues, various types of automated equipments have been developed for the purpose of pavement monitoring and evaluation.

Visual observation of pavement distress is the most common method for monitoring pavement surface condition. This has been traditionally performed by trained engineers who work or drive along the road and count the distresses (Oh, 1998). However this method of field inspection poses several drawbacks, such as:

- (i) Slow, labour intensive and expensive.
- (ii) Subjective approach generating inconsistencies and inaccuracies in the determination of pavement condition.

- (iii) Inflexible and does not provide an absolute measure of the surface.
- (iv) Has poor repeatability since the assessment of given pavement section may be differ from one survey to the next.
- (v) Could expose a serious safety hazard to the surveyors due to high speed and high volume traffic.

Numerous system users believe that there is a need to minimise the drawbacks listed above, replacing manual data collection system with automated systems. In response to these demands, various studies have been conducted to apply new technologies in pavement monitoring. Consequently, automated pavement condition data collection and processing have become important study topics. The size, shape, and variations of each distress type, as well as the variations of the texture and colour of the pavement surface, present a challenge to researchers (Li *et al.*, 1991).

Among these technologies, close-range digital photogrammetry is seen as a possible approach in providing accurate, consistent data and easy visualisation for pavement distress studies. Furthermore, a combination of a close-range digital photogrammetry data collection system and suitable image processing analysis would result in a system which is reliable and dependable. Therefore, this study looks at developing a photogrammetric based pavement evaluation approach by utilising ortho-image and image processing techniques.

### **1.3 Objectives**

In recent years, there has been significant advancement in computer and image sensor technologies. Therefore, this study is directed towards investigating computer and image sensor technologies to automate pavement image data collection and analysis.

The objectives of this study are to:

- (i) investigate the use of a stereovision measurement technique in evaluating and monitoring pavement conditions,
- (ii) provide an automated pavement imaging program using existing software, and
- (iii) assess the performance of the proposed method with respect to accuracy and practicality.

### **1.4 Scope of Investigation**

This study was undertaken to capture pavement images using digital camera and subsequently processing them using computers to quantify pavement distresses.

Therefore, the scope of this thesis can be summarised as:

- (i) applying close-range digital photogrammetry approach in creating ortho-image and 3D model of pavement,

- (ii) developing suitable image processing algorithms in classifying and quantifying different types of cracking,
- (iii) providing a pavement distress severity in accordance to guidelines set by the government authority (JKR), and
- (iv) assessing the performance of the proposed method against existing methods in terms of accuracy, user-friendliness and reliability.

## **1.5 Hypotheses**

The implementation of close-range digital photogrammetry and image processing techniques yield a system that is accurate and reliable in automated pavement distress analysis.

## **1.6 Limitations**

In this research, the application of the close-range digital photogrammetry and image processing techniques were limited to flexible pavement (asphalt concrete surface) distresses analysis, such as disintegration and cracking. Concrete pavements analysis was not performed.



Images of pavement surface were captured during the day under ambient light and dry conditions. This is because, images taken with such conditions are better compared to those taken under direct sunlight.

Accuracy of the stereovision system is dependant on the resolution of charged couple device (CCD) camera used (2.0 Mega pixels).

### **1.7 Significance of the Research**

- (i) A three-dimensional analysis with both quantitative and qualitative data extraction is proposed.
- (ii) The existing manual inspection is replaced due to its limitations.
- (iii) An alternative method in automated pavement evaluation systems, which is viable to be used in pavement maintenance, is provided.

## **1.8 Thesis Outline**

This thesis consists of five chapters. Presentation of the findings of the present investigation begins in Chapter II with a literature review describing the background of this study. The type of pavement distresses, developed pavement evaluation methods and the existing image processing techniques for pavement analysis are reviewed. Consequently, the overview concept and theory involved in photogrammetry are discussed.

Chapter III explains the processes to be followed in using the stereovision measurement technique. In addition, this chapter describes the digital image processing algorithms developed, including cracking classification and quantification. Simple manual method assessments are discussed.

Chapter IV presents the results obtained from the proposed methods and conventional methods. Both results are compared and validated using a statistical test.

Chapter V, discusses and concludes the finding of this thesis. Future work on this topic is also suggested.

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