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

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A thesis submitted in fulfilment
of the requirements for the award of the degree of
Master of Engineering (Highway & Traffic)

Faculty of Civil Engineering
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APRIL 2005

Dedicated to Jesus Christ,

My personal Lord and Savior,

And

To my beloved parents and family.

ACKNOWLEDGEMENT

This study would not have been possible without the assistance and support of those who guided me in the course of my graduate work. First, I would like to thank God for His grace and mercy throughout this research. It is by His hands and wisdom in guiding me to finish my work within the study period.

Second, I would like to extend my thanks to my honorable supervisor, Assoc. Prof. Dr. Mushairry Mustaffar, for his support, encouragement, and academic guidance during the course of my study. I would like to specially thank his patience and tolerance towards me, in which he always trusts me that I am able to do it. His diligence, dedication and working attitudes are good examples for me to follow.

Third, I would also like to thank my co-supervisor, Assoc. Prof. Dr. Othman Che Puan for his ideas and valuable suggestions which allowed me to gain a broader understanding of my research.

Last but not least, I am grateful to my family members for their love, support and encouragement.

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

Kebolehkhimatan 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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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
$\overline{G}$	-	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, σ	-	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
π	-	Pi
λ	-	Scale factor
ω, φ, κ	-	Rotation angles
μ	-	Mean
α	-	A singificant level
γ	-	Density
H_a	-	Alternative hypothesis
H_o	-	Null hypothesis
t_α	-	t statistic value

LIST OF APPENDICES

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.

REFERENCES

AASHTO (1974). *Interim Guide for Design of Pavement Structural*. Washington, D. C.: American Association of State Highway and Transportation Officials.

Acosta, J. A. (1991*) Pavement Surface Distress Evaluation Using Video Image Analysis*. Case Western Reserve University: Ph.D. Thesis.

Acosta, J. A., Figueroa, J. L. and Mullen, R. L. (1994). *Implementation is Video Image Processing technique for Evaluating Pavement Surface Distress in the State of Ohio*. Case Western Reserve University, Final Report No. FWHA/OH-94/005.

Baker, J., Dahlstrom, B., Longenecker, K., and Buu, T. (1987). Video Image Distress Analysis Technique for Idaho Transportation Department Pavement Management System. *Transp. Res. Record*. 1117.

Benson, K., Elkins, G., Uddin, W. and W. Hudson (1988). Comparison of Methods and Equipment to Conduct Pavement Distress Survey. *Transp. Res. Record*. 1196: 40-50.

Brown, D. C. (1968). *Advanced Methods for the Calibration of Metric Cameras*. Technical Report DA-44-009-AMG-1457. Melbourne, FL: DBA System.

Brown, D. C. (1971). Close-Range Camera Calibration. *Photogrammetric Engineering and Remote Sensing*. 37 (8): 855-866.

Burson, E. (2001). Geospatial Data Content, Analysis, and Procedural Standards for Cultural Resources Site Monitoring. *Miscellaneous Report of Investigations*. Number 218.

Carbonnell, M. (1989). Architectural Photogrammetry. In: Karara, H. M. *Non-Topographic Photogrammetry*. Falls Church, Virginia: American Society for Photogrammetry and Remote Sensing. 321-347.

Cheng, H. D., and Miyojim, M. (1998). Automatic pavement distress detection system. *Journal of Information Sciences*. 108: 219-240.

Clohessy, K. (1996). Using Object-Oriented Programming Tools to Build Real-Time Embedded Systems. *Real-Time Engineering*. 3 (3): 8-26.

Dhond, U. and Aggrawal, J. (1989). Structure from Stereo. *IEEE Transaction Systems, Man, and Cybernetics*. 19(6): 1489-1510.

El Sanhouri, I. M. (1990). *Computer-Based Segmentation and Interpretation of Pavement Surface Distress Images*. Massachusetts Institute of Technology: Master of Science Thesis.

Fukuhara, T., Terada, K., Nagao, M., Kasahara, A., and Ichihashi, S. (1990). Automatic Pavement-Distress-Survey System. *J. Transp. Engrg, ASCE*. 116 (3): 280-286.

Gisiger, A., E. Cooper, Y. Yuan, and W. F. Limp (1996). *Development and Implementation of a Rapid Low-Cost Photogrammetric Data Archival System for Artifact and Osteological Inventory*. Center for Advanced Spatial Technologies. University of Arkansas, Fayetteville.

Grivas, D. A., Bhagvati, C., Skolnick, M. M., and Schultz, B. C. (1994). Feasibility of Automating Pavement Distress Assessment Using Mathematical Morphology. *Transp. Res. Record*. 1435: 52-58.

Haas, C., and Hendrickson, C. (1991). Integration of diverse technologies for Pavement Sensing. *Transp. Res. Record*. 1311: 92-102.

Haas, R., and Hudson, W. R. (1978). *Pavement Management Systems*. New York: McGraw-Hill, Inc.

Haas, R., Hudson, W. R., and Zaniewski, J. (1994). *Modern Pavement Management*. Krieger Publishing Company.

Hintz, R. J., Karakadas, C., and Kang, J. M. (1989). Analysis of Pavement Cracking and Rutting Using Close-range Photogrammetry. *Photogrammetric Engineering and Remote Sensing*. 55(2): 217-221.

Jain, A. K. (1989). *Fundamentals of Digital Image Processing*. Englewood Cliffs, NJ.: Prentice Hall.

Jitprasithsiri, S. (1997). *Development of a New Digital Pavement Image Processing Algorithm for Unified Crack Index Computation*. The University of Utah: Ph.D. Dissertation.

JKR (1992). *A Guide to Visual Assessment of Flexible Pavement Surface Conditions.* Malaysia: Jabatan Kerja Raya Malaysia.

Kadiyali, L. R. (1984). *Principles and Practice of Highway Engineering*. New Dehli: Khanna. 371-372.

Kaseko, M. S., Lo, Z. P., and Ritchie, S. G. (1994). Comparison of Traditional and Neutral Classifiers for Pavement-Crack Detection. *J. Transp. Engrg, ASCE*. 120(4): 552-569.

Kelvin C. P. Wang (2000). Designs and Implementations of Automated Systems for Pavement Surface Distress Survey. *J. Transp. Engrg, ASCE*. 6(1): 24-32.

Kim, J. (1998). *Development of a Low-Cost Video Imaging System for Pavement Evaluation*. Oregon State University: Ph.D. Thesis.

Kittler, J and Illingworth, J. (1986). Minimum Error Thresholding. *Pattern Recognition*. 19(1): 41-47.

Koutsopoulos, H., and Downey, A. B. (1993a). Primitive-Based Classification of Pavement Cracking Images. *Journal J. Transp. Engrg, ASCE*. 119(3): 402-418.

Koutsopoulos, H., El Sanhouri, I., and Downey, A. B. (1993b). Analysis of Segmentation Algorithms for Pavement Distress Images. *J. Transp. Engrg, ASCE*. 119(6): 868-888.

Lanphair, H., and Larsen, T. R. (1996). Applications of 3-D and 4-D Visualization Technology in Transportation. *NCHRP Synthesi, Transportation Research Boards*. 229.

Lee, H. (1990). Evaluation of Pavedex Computerized Pavement Image Processing System in Washington. *Proceeding of the 1990 Automated Pavement Distress Seminar, Federal Highway Administration.* 205-224.

Lee, H., and Oshima, H. (1994). New Cracking Imaging Procedure Using Spatial Autocolletion Function. *Journal J. Transp. Engrg, ASCE*. 120(2): 206-228.

Lemmens, M (1988). A Survey on Stereo Matching Techniques. *ISPRS International Archives of Photogrammetry and Remote Sensing*, Congress Kyoto, Kyoto, Japan. 27(4) Part B8: 11-23.

Lewis, R. (1990*). Practical Digital Image Processing*. England: Ells Horwood Limited.

Li, L., Chan, P., and Lytton, R. L. (1991). Detection of Thin Cracks on Noisy Pavement Images. *Transp. Res. Record*. 1311: 131-135.

Mahler, D.S., Kharoufa, Z. B., Wong, E. K., and Shaw, L. G. (1991). Pavement Distress Alaysis Using Image Processing Techniques. *Microcomputers in Civil Engineering*. 6: 1-14.

Maser, K. R. (1987). Computation Techniques for Automated Visual Inspection. *Working paper*. MIT, Cambridge. Unpublished paper.

McNeil, S., and Humplick, F. (1991). Evaluation of Errors in Automated-Distress Data Acquisition. *J. Transp. Engrg, ASCE*. 177(2): 224-241.

Mikhail, E. M., Bethel, J. S. and McGlone, J. C. (2001). *Intoduction to Modern Photogrammetry*. New York: John Wiley & Son, Inc.

Miyojim, M. (1996). *Detection and Classification of Pavement Distress Through Image Skeletons*. Utah State University, Logan, Utah: Master Thesis.

Morris, J. (1973). The prediction of permanent deformation in asphalt concrete pavement. *Rep., Transport Group*, Dept. of Civ. Engrg., Univ. of Waterloo, Ontario, Canada.

Mustaffar, M., Che Puan, O., and Ling, T. C. (2004). Application of Digital Photogrammetry to Quantification of Road Surface Distresses. *6th Malaysian Road Conference*. 16-18 August. Kulau Lumpur, Malaysia.

Obaidat, M. T., and Al-Masaeid, H. R. (1998). Video System to Monitor Archeological Sites Using Ground-Based Photogrammetry. *Journal Survey Engineering, ASCE*. 124(1): 3-25.

Oh, H. (1998). *Image Processing Technique in Automated Pavement Evaluation System*. University of Connecticut: Ph.D. Dissertation.

Otsu, N. (1979). A Threshold Selection Method from Gray-Level Histogram. IEEE Transactions on System, Man, and Cybernetic. SMC-9(1): 62-66.

PASCO (1984). *PASCO Road Survey System for Pavement Maintenance and Repair Planning*. Road Survey Department, Tokyo, Japan: PASCO Corp.

Ritchie, S. G. (1990). Digital Imaging Concepts and Applications in Pavement Management. *Journal Survey Engineering, ASCE*. 116(3): 287-298.

Scrivner, F. H. and Moore, W. M. (1968). An Empirical Equation for Predicting Pavement Deflections. *Research Report*. 32: 13.

Shahin, M., and Kohn, S. D. (1981). Pavement Maintenance Management for Roads and Parking Lots. *Report TR m-394*, Constr. Engrg. Res. Lab., U.S. Army Corps of Engrs., Champaign, III.

SHRP-P-338 (1993). *Distress Identification Manual for the Long-Term Pavement Performance project*. Washington, D.C.: Strategic Highway Research Program.

Simpson, A. L. (2001). *Measurement of Rutting in Asphalt Pavements*. The University of Texas, Austin: Ph.D. Dissertation.

Wang, Z. (1990). *Principles of Photogrammetry*. Press of Wuhan Technical University of Survey and Mapping. Beijing: Publishing House of Surveying and Mapping.

Wolf, P. R. (1983). *Elements of Photogrammetry*. 2nd ed. New York: McGraw-Hill.

Wolf, P. R., and Dewitt, B. A. (2000). *Elements of Photogrammetry, with Applications in GIS*. 3rd ed. Boston: McGraw-Hill.

Yoder, E. J. (1964). *Principles of Pavement Design*. New York: John Willy & Sons, Inc.

Yoder, E. J. and Witczak, M. W., (1975). *Principles of Pavement Design*. 2nd ed. New York: John Willy & Sons, Inc.