MICHIGAN OHIO UNIVERSITY TRANSPORTATION CENTER
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Report No: MIOH UTC TS18p2-3 2010-Final-UDM

TRANSPORTATION INFORMATICS: ADVANCED IMAGE PROCESSING TECHNIQUES FOR AUTOMATED PAVEMENT DISTRESS EVALUATION

FINAL REPORT

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Report No: MIOH UTC TS18p2-3 2010-Final-UDM

TS18, Series, UDM Projects 2-3, September, 2010
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SPONSORS

This is a Michigan Ohio University Transportation Center project supported by the U.S. Department of Transportation, the Michigan Department of Transportation (for the University of Detroit Mercy portion of the project), The University of Toledo, and the University of Detroit Mercy.

ACKNOWLEDGEMENT

The project team would like to acknowledge support from the Michigan Department of Transportation (MDOT) during the course of this research. Also the project team would like to acknowledge collaboration with researchers from The University of Toledo.

DISCLAIMERS

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ABSTRACT

Pavement condition assessment is a critical part of infrastructure management; however, the process of collecting and analyzing the necessary data is time consuming. Furthermore, the conclusions obtained from the analysis of pavement condition data are subjective. Methods to reduce the time required to collect and analyze the data or to reduce the subjectivity in the interpretation of the data could be beneficial to parties responsible for the management of pavement structures. Two methods have been proposed, each of which addresses one of the limitations of the existing methods of pavement condition assessment.

The first method is the development of a computerized interface and database for pavement condition assessment from digital photographs. The intent of using digital photographs rather than a windshield survey for data collection is to allow easier identification of conditions and to allow easy re-evaluation in the event of discrepancies among the results obtained by individual inspectors.

The second method is to apply image processing techniques to the pavement condition assessment process from digital photographs. The intent of using digital photographs and image processing techniques is to automate the pavement condition assessment process, thereby removing the subjective nature of manual assessment.

This project began in January 2009, and this report covers work completed through December 2009, which is the time period during which the project received support from the Michigan Department of Transportation. The work continued beyond December 2009, using funds from the United States Department of Transportation and the University of Detroit Mercy. During that time period, the researchers at the University of Detroit Mercy developed a computer interface which allows the user to review digital photographs from Google Earth, identify defects present.

TABLE OF CONTENTS

PAGE

LIST OF FIGURES

PAGE

1. Introduction

Roads are part of the infrastructure that must be constructed, maintained, repaired, and eventually replaced, and each of these tasks requires resources. The resources associated with road construction, maintenance, and repair includes the labor, equipment, and material associated with design services, material testing, demolition, and construction. During a project consisting of road maintenance, repair, or reconstruction, the traffic that normally uses that road will be delayed (at the least) and possibly re-routed, and these delays will have an economic impact on drivers, residents, and businesses. The general state of the infrastructure in the United States is poor, and the cost of upgrading the nation's infrastructure to acceptable levels is $2.2 trillion (1). Specifically, roads were rated as D- (1). Given the amount of resources, including money, associated with upgrading the nation's infrastructure, including roads, to acceptable levels, and the amount of resources associated with new road projects, the stakeholders in these projects need to carefully allocate these resources.

Asset management is a formalized process that allows stakeholders to optimize the allocation of resources for activities such as construction, maintenance, repair, and replacement of their systems or infrastructure. Asset management principles applied directly to pavement is generally called pavement management. A pavement management program includes collecting and analyzing data on the use and condition of roads within the subject network (2). The results of the use and condition analysis could be used to forecast future use and condition, to make strategic decisions, and to prioritize resource allocation.

Pavement condition is determined by identifying the type, severity, and extent of various defects or modes of deterioration and assigning a condition value to the pavement. Some of the common pavement condition assessment methods include the Federal Highway Administration (FHWA) method, the Pavement Surface Evaluation and Rating (PASER) method, and pavement condition index (PCI) method. In all of these methods, a condition number is assigned from the results of a windshield survey, which is a visual inspection of the pavement performed while driving the subject road.

Some limitations of this visual inspection are the effort required to obtain the results, trade-offs between the data collection process and the quality of the data, and the variability in the results. Furthermore, if the assessment data are collected from a windshield survey, the survey could interfere with traffic flow or traffic flow could obscure some of the conditions that the evaluators would need to note.

The trade-offs between the effort required to obtain the results and the quality of the data can be illustrated through the results of a study performed by the Kent County Road Commission (KCRC) in 2001 (3). Prior to 2001, the KCRC had been using the PCI method for pavement condition assessment. Based on the procedures associated with the PCI method and the size of the KCRC network, only one-third of the network could be evaluated in any given year. The KCRC undertook a research project that involved evaluating the roads using both the PCI and PASER method and comparing the results in terms of cost of data collection and processing, type of data collected, and recommended action from the results.

The outcomes were that effort associated with data collection and processing using the PASER method were such that the entire network could be evaluated in one year, compared to three years by the PCI method; and that the recommended course of action based on the evaluation results were generally similar. The downside of assessing pavement condition with the PASER method is that the PASER method does not provide the level of detail of the PCI method.

The repeatability of pavement evaluation can be addressed by having several inspectors evaluate the same subject road several times and by different methods. In one such study, a team of three inspectors evaluated the same road twice using visual inspection of the subject road and twice using visual inspection of digital photographs of the subject road. The results were that the variability between inspections ranged from 41 to 43 percent for visual inspection of the subject road, compared to 8 to 19 percent from visual inspection of digital photographs of the subject road (4).

Assessing pavement condition by visual inspection, whether the data are collected from a windshield survey or from photographs, is subjective in that it relies on interpretation from a human inspector. Non-destructive test methods, such as the falling weight deflectometer (FWD) and the international roughness index (IRI) have been developed to provide pavement condition. The FWD is performed with an impulsive force applied with a drop weight and a series of transducers to measure the response of the pavement-soil system. The results are analyzed to determine the elastic constants of the pavement, aggregate base, and subgrade (5). The results of the IRI are the roughness (6). Both of these methods require trained operators and instrumented vehicles, and will cause some traffic delay during testing.

Techniques from digital signal processing have been proposed and tested as a method to automatically identify and quantify various types of defects in pavement (7). The intent of these methods is to remove the subjective nature of human interpretation from the pavement condition assessment process.

As the size of the nation's road network increases, the resources required to maintain this network will increase, and that includes inspection. Some challenges for those agencies responsible for condition assessment include obtaining enough data to make strategic and specific decisions, and obtaining those data economically and reliably.

This is a report on the first phase of a project that will result in a computerized interface for the evaluation of pavement condition using digital photographs and the development of a computerized database of the pavement condition assessment results.

2. Background

Asset management allows stakeholders to systematically collect, organize, and analyze data related to the performance and condition of buildings, utilities, pavements, etc., for which that stakeholder is responsible. Ultimately, decision-makers can better allocate resources related to the operation of that asset.

Pavement is an asset that stakeholders, such as state and local governments, must construct, maintain, repair, and eventually replace. A pavement management system is a specific form of asset management that allows the stakeholders to allocate resources for the pavement system.

A key element of a pavement management system is collecting and analyzing pavement condition data. The traditional methods of pavement evaluation rely on teams of investigators driving the subject site and making notes as they drive. This method is time-consuming and subject to operator error. An attempt to improve pavement evaluation is to use digital photographs, typically taken with specially instrumented vehicles.

3. Pavement Management Systems

Medina et al. (1999) cited a portion of the *Pavement Policy for Highways* that defines pavement management as, "a set of tools or methods that can aid decision-makers in finding cost-effective strategies for providing and maintaining pavements in a serviceable condition" (8). The pavement management system must address methods, schedules, and budgets associated with achieving the goals.

The three main components of a pavement management system are data collection, data analysis, and implementation. One approach to pavement management is shown schematically in Figure 1.

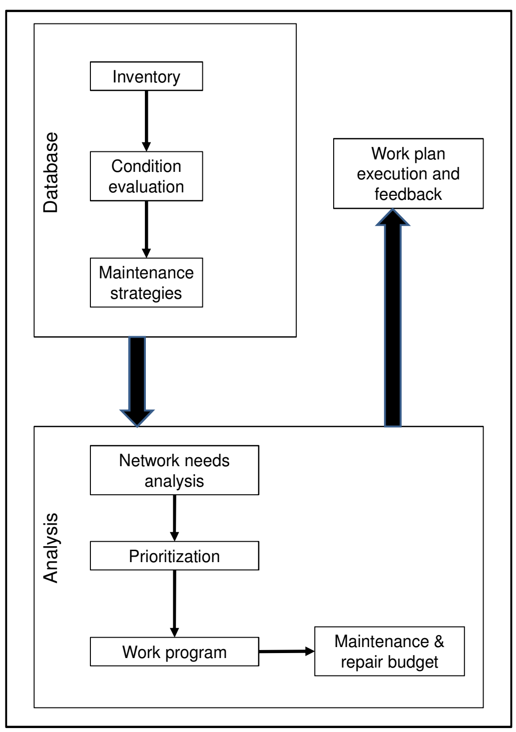

Figure 1: Pavement Management Structure
(after Medina et al., 1994)

The data collection component is summarized in a database which includes the inventory, condition evaluation, and maintenance strategies. The analysis portion of the Pavement Management Structure requires the synthesis of the pavement condition assessment, which is determined from the condition evaluation and the maintenance strategies, along with global concerns related to the network. Based on the results of the network need, one can prioritize the work and develop a work plan, which is, of course, constrained by budgets. Once projects have been selected that are high on the priority list and feasible within the budget, they are implemented.

4. Pavement Condition Assessment

Pavement condition assessment is the process by which existing pavement structures are evaluated to identify conditions that could affect ride quality, rider safety, or structure life. Numerous pavement condition assessment methods have been developed, but all of them have common features such as:

- Type of condition
- Severity of condition
- Extent of condition

Once the assessment has been completed, decisions could be made related to maintenance, repair, or reconstruction of the pavement.

The PASER method is the pavement condition assessment that was developed by researchers at the University of Wisconsin-Madison (9). Pavement structures evaluated by the PASER method are rated from 10 (excellent condition) to 1 (failed pavement), based on the type, severity, and extent of the observed conditions. In general, structural problems of low severity result in a lower PASER rating than non-structural problems of higher severity. For example, a longitudinal crack that develops along a construction joint derives from quality during construction and is not a structural condition. If the longitudinal crack width is small, i.e., less than one-quarter inch, the PASER rating is 8, which is considered "Good." On the other hand, rutting represents structural failure of the pavement. Even minor rutting, i.e., depth less than one-half inch, results in a PASER rating of 3, which is considered "Poor."

In the method developed by the FHWA, the conditions that could affect ride quality or ride safety, or that represent structural defects, have been identified and classified as Low Severity, Medium Severity, or High Severity (10). The presence of different conditions, their severity, and extent are used to determine the overall pavement condition.

In the PCI method, the type, severity, and extent of each condition is identified and the overall pavement condition is rated from 1 (failed) to 100 (no defects) using the evaluation procedures of the PCI method (3).

5. Database Types and Characteristics

A database is a model that stores values such that relationships can be easily identified and results can be easily analyzed. According to Ullman and Widom (2008), all data models, whether databases or otherwise, require the developer to define:

- The structure of the data
- Operations on the data
- Constraints on the data (11)

In a database, the structure of the data is a two-dimensional array called a *table*. The table is comprised of *records*, and each record contains *fields*. The data in a particular field could be numeric, string, logical, etc. The fields in a record can contain mixed data types, but once a data type is selected, all records for that field must follow the selected data type. The operations on the data are called *queries*, and can include isolating certain records or fields within each record based on user-defined criteria. For example, the user may decide to identify all records for which a field is greater than a threshold value. The constraints on the data depend on the type of data. For example, if a particular field is the month, it must fall between 1 and 12 for numerical data or must contain the name of a month for string data.

The results of data operations performed on a data structure that meets the defined constraints are presented as *reports*. Common report formats include tabular and graphical. Furthermore, graphical reports could be graphs or drawings.

Graphical information system (GIS) is a software package that combines database functions with computer-aided drafting (CAD) and mapping capabilities. It is well-suited to analyze data from a database and generate graphical reports as drawings. The drawings could be generated with the CAD features of the GIS software or could be overlain on maps that are imported from another software package.

6. Image Processing

The content of a photograph will contain one or more objects of interest, i.e., the subject of the photograph, but also will contain a background, and may contain objects that are not part of the subject of the photograph. The interpretation of photographs includes identifying and classifying objects of interest captured in the photograph, and may include quantifying these objects.

In the case of digital photography, the image is discretized into a set of pixels. The number of pixels in a photograph depends on the resolution of the camera, the size of the lens, and the distance from the camera to the subject of the photograph. Another way of thinking about a digital photograph is the scale of the pixel. Each object in the photograph is a certain size and is captured by a certain number of pixels. From this information, the scale of each pixel can be computed. In theory, the objects of interest in a digital photograph can be quantified by determining the scale of the photograph and counting the number of pixels required to capture each object of interest.

Some challenges in quantifying the contents of a digital image are illumination, noise, and ill-defined boundaries between objects and background. Image processing is a field that attempts to improve the probability of identifying, quantifying, and analyzing objects of interest within a digital photograph.

The basic steps in the processing of a digital image are coding, enhancement, restoration, and feature extraction (12). Image coding is the process of collecting the data. Image enhancement includes isolating features of interest or removing items that are not of interest. Image restoration can include reducing the effects of uneven illumination and of noise. Image feature extraction consists of determining the desired characteristics of the objects of interest. A common method of removing noise from images is filtering (13).

7. Results of Investigation

The goal of this project is to develop an interactive pavement condition database system that could be used as part of a pavement management system. This project, which is being conducted in conjunction with a similar project at the University of Toledo (UT), was first funded in January 2009 and is presently funded through August 2009. At the beginning of the UDM portion of this project, the researchers at UT are currently in Year 2 funding through the MIOH UTC.

The activities of the project completed thus far by the researchers at UDM have been to:

- Review general topics within pavement condition assessment;
- Review general topics within databases;
- Review the methods used for pavement condition assessment within the state of Michigan; and
- Design an interface and database that incorporates aspects of successfully developed pavement condition assessment systems but meets the criteria used within the state of Michigan.

The researchers at UDM met with researchers at UT, who had begun their research a year in advance of the researchers at UDM. The outcomes of the meetings at UT were:

1) Pavement Condition Assessment
   a) The researchers at UT use the FHWA method of pavement evaluation.
   b) The researchers at UT analyze digital photographs to assess the pavement condition (some of these photographs have been collected by the researchers and some have been collected from Google Map.)
   c) The researchers at UT have developed a computerized database and interface to analyze the digital photographs of pavement sections and to determine the condition of those pavement sections using the FHWA method.

2) Digital Image Processing applied to Digital Images of Pavement
   a) The researchers at UT have collected digital images of pavements sections with varying types of defects.
   b) The researchers at UT have developed methods to automatically isolate the defect portion on a digital photograph of pavement surface that contains defects.
   c) Quantify the defects identified in Step 2b.

8. Pavement Condition Assessment

The standard method of pavement condition assessment in the state of Michigan is the PASER method. The PASER rating is most often determined through a windshield survey, although the use of digital photographs for manual interpretation is becoming more common (3).

The inspectors collect the data by driving the subject road, recording observations, and rating the road. The inspectors compare their results and, if the results are acceptably close to each other, the average of the results becomes the rating. If the results are not acceptably close to each other, the road would be evaluated again, presumably by driving it again.

One method of improving the evaluation of road is to collect digital photographs of the road and determine the pavement condition from the photographs. The evaluation could be performed at the office or laboratory after all photographs have been collected. An advantage of this method over evaluation during driving is that if the results do not match, the team of inspectors could re-evaluate the road from the photographs rather than by driving the subject road again.

The method of evaluating roads from digital photographs is, theoretically, less expensive than evaluating the roads by driving them; however, it is still expensive in that it requires specially instrumented vehicles. Researchers at UT have developed a method of evaluating pavement from digital photographs collected through Google Earth.

The UDM researchers have met with the UT researchers to review their procedures and interface. The UT researchers evaluate their pavement using the FHWA method; whereas, the UDM researchers would use the PASER method. Because the pavements are evaluated by different methods, the UDM researchers would need to develop a new interface and database. At this time, the UDM researchers have identified a set of criteria for the interface and database and have begun the design of these systems.

The UDM researchers used the requirements of the PASER method and the concepts presented during the meeting with the UT researchers to develop a computerized interface for pavement evaluation and database for the management of that pavement evaluation data. The interface was coded in visual basic and the details of that interface are shown in Figure 2.

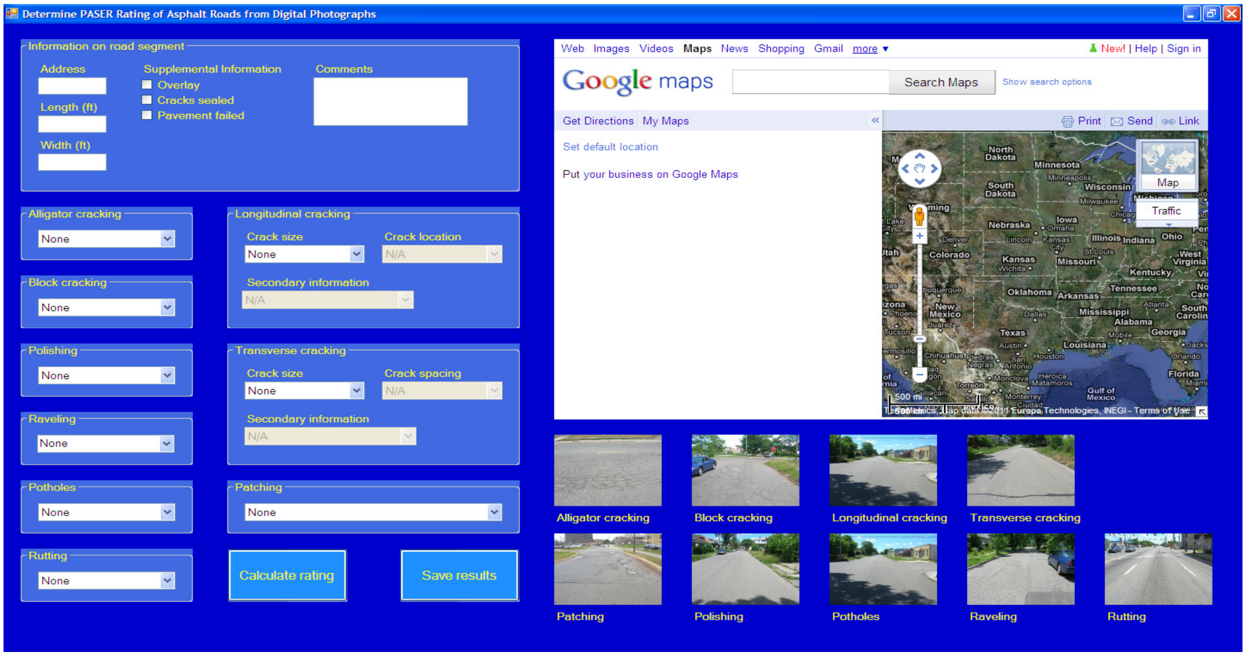

Figure 2. Computerized Interface for Pavement Evaluation by PASER Method

The interface has distinct areas related to the general information on the road segment, the image of the road segment, the conditions identified in the evaluation, and conditions. The upper left-hand corner of the interface has a set of text boxes in which the user can enter basic information on the segment, such as address, width, and length. This portion also includes check boxes for specific conditions that automatically define the PASER value, i.e., “Recent Overlay” and “Failed.” The upper right-hand corner is a Web browser that allows the user to review the photographs. Below the Web browser are sample photographs of the nine conditions considered in the PASER method. Most of the left side contains drop-down menus in which the user selects the conditions present and the severity of these conditions. The “Calculate rating” button executes code that parses the contents of the drop-down menus and check boxes to determine the PASER number. The “Save results” button executes code that performs the same function as the “Calculate rating” button but it also writes the results to the database.

The functionality of the interface and the concept of using digital photographs from Google Earth were tested by evaluating several stretches of road for which PASER results were available and then comparing the two sets of results. The city of Novi, Mich., was selected and the results of the 2008 evaluation of that city’s road network were used as the test case (14). Several roads of low, medium, and high traffic were selected. The results indicate that the pavement evaluation using digital images found on Google Earth were ±1 of the results presented in the 2008 evaluation. Other road segments were evaluated, but those results could not be compared to published values because the researchers did not have access to reports on the evaluation of those roads.

From the results of the Novi evaluation and of other roads, a preliminary finding is that digital images available on Google Earth provide a good first pass at pavement evaluation but will probably not replace digital images collected with specially instrumented vehicles designed for the collection of pavement condition data, nor will they replace windshield surveys. Not every road of interest will be in the Google Earth database, and the quality of photographs in that database could vary significantly. A particular concern is the availability of images of wide roads or divided roads. The images collected for Google Earth appear to be collected as the vehicle drives one direction in one lane of the road. If the road is wide or divided, the pavement on the opposite side of the road may not be visible.

The researchers at UDM have begun working with Arc Map GIS to develop methods of graphically presenting results from pavement condition assessment projects.

9. Digital Image Processing Applied to Digital Images of Pavement

The researchers at UT have developed a method of automatically identifying and quantifying cracks in pavement by applying techniques from digital image processing to digital photographs of pavement. The images were collected with a digital camera. The image enhancement was performed with median filtering. After the image was enhanced, pixels corresponding to cracks were identified. The pixels corresponding to cracks were analyzed to determine direction and connectivity, and to determine the size of the cracks.

10. Next Steps

The next steps in this research project are to add functionality to the computerized interface and database, and to link the contents of the pavement condition database to an Arc Map GIS database. Once all of the functions have been added to the database, a formal study will be undertaken to identify advantages and disadvantages of pavement condition assessment using digital images available through Google Earth.

11. List of Acronyms

CAD	Computer-aided drafting
FWD	Falling weight deflectometer
FHWA	Federal Highway Administration
GIS	Graphical information system
IRI	International roughness index
KCRC	Kent County Road Commission
PASER	Pavement Surface Evaluation and Rating
PCI	Pavement condition index

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