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Video Image Processing for Evaluating Pavement Surface Distress

An NCHRP digest of the findings from the final report on NCHRP Project 1-27, "Video Image Processing for Evaluating Pavement Surface Distress," *conducted by Triple Vision, Inc., Dr. Richard A. Fundakowski, Principal Investigator.*

THE PROBLEM AND ITS SOLUTION

Measuring distress of both bituminous and portland cement concrete pavements is a primary means of evaluating pavement performance. However, current methods of obtaining distress measurements, often involving on-site recording of each distress, are both subjective and time consuming. An increasing number of transportation agencies have embraced the concept of data- and image-acquisition systems that record, among other things, the condition of the pavement surface in a video format. An automated means of processing video images to quantify surface distress would represent a significant contribution in the field of pavement management at both network and project levels.

NCHRP Project 1-27 was initiated in response to this need. The objective of the research was to develop a system for processing video images to identify, quantify, and classify pavement distress in terms of types, severity, and extent.

The final report on NCHRP Project 1-27, "Video Image Processing for Evaluating Pavement Surface Distress" documents the development and evaluation of an image processing system designed to process video images of the pavement surface and thereby identify and quantify pavement surface distress. The general research approach used was to investigate image processing and pattern recognition techniques to categorize pavement distresses as to type, severity, and extent. Based on an initial prioritization, the development was focused primarily at various forms of cracking and the detection of joints and their deterioration. The development culminated in the integration of the most promising concepts into an image processing system, which processed images stored on a video disk and output an inventory of the detected distress types, severity, and extent. The video image processing system was evaluated by a comparison of the system's generated output with a corresponding visual interpretation for several sets of video images pavement sections. The system's findings showed good overall correspondence with the visual surveys, in detecting a variety of types of cracking on both asphalt-surfaced and PCC pavements. The system also reliably distinguished joints from cracks. The report includes hardware and software recommendations that can be directly applied by the user highway agencies in selecting equipment for acquiring and processing video images of the pavement surface.

FINDINGS

NCHRP Project 1-27 has demonstrated a video image processing system which employs image processing and pattern recognition techniques for interpreting pavement surface distress. The video image processing system that was developed during this project shows potential for discerning isolated and patterned cracking on both asphalt and PCC pavements. It is also capable of assessing joint deterioration and discriminating joints from cracks on PCC pavements. The project sought to demonstrate the capability to discern pavement distress through a quantitative comparison with distress surveys gathered by visual interpretation of the video data by trained pavement engineers. It was felt that such a comparison provides an assessment of the technology relative to the current practice -- the visual survey. Using this approach, trained reviewers visually interpreted the video data for 30 sections of pavement, comprising more than 3,000 images of video data, and their findings were compared with the output of the system.

The results showed that the system was very effective at detecting surface cracking, when gauged against the results of the visual surveys. In comparison to the results of the visual surveys, the system typically exhibited an error in the range of 5 percent to 17 percent in its estimate of the extent of the distress. The system was over 95 percent effective in detecting cracks that were 3 or more pixels in width. The system did tend to estimate consistently higher severities than was reported by the visual interpretations. This was believed to be a direct result of the video image processing system applying strict quantitative rules (e.g., moderate severity, if mean crack width is less than 0.5 in.), while the reviewers could incorporate additional subjective observations in the evaluation (e.g., the degree of spalling). Using additional video data collected with a camcorder, it was shown that with adequate camera resolution the system could detect cracks as fine as 1/16 in.

The system reliably distinguished cracks from joints. However, the system's estimate of the severity of joint deterioration was consistently higher than the results derived from the visual surveys of the same video data.

Based on the development and evaluation conducted during the course of project, it is felt that image processing has the immediate potential for quantifying most types of cracking, limited only by the resolution and general quality of the video image data. Refinement is needed of the criteria used by the video image processing system for categorizing the severity of the distress in order to better approximate an agency's specific definitions of severity. The ability to accurately detect and quantify the broader set of pavement surface distresses will require additional development and testing.

The options for collecting and processing the video data are numerous. Film has the distinct advantage of offering superior resolution. It is also particularly attractive as a storage medium to transfer data from the field to the laboratory for interpretation. However, there currently is no readily available means of retrieving the high quality data from the film as equivalently dense array of picture elements which can then be either displayed or processed. The missing link, at present, is the film scanner.

Existing systems, which perform data collection with standard video cameras and recording, have the ability to produce recorded data in a format that can be readily displayed and processed, but cannot achieve the resolution of film. If a state agency determines that its needs require ability to detect hairline cracks, tests should be conducted with any proposed equipment to determine its adequacy in collecting the required data.

The processing of video data for pavement surface distress evaluation using the techniques developed in this project requires special-purpose computing hardware to achieve practical processing rates. This specialized hardware would consist of several computer boards tailored to performing image processing operations. The software developed provides a complete representation of the techniques used by the project to perform the pavement distress evaluation from video data. An agency wishing to employ this technology must implement these or equivalent techniques on the selected processing platform.

CONCLUSIONS

General

Using video images acquired from film proved adequate for human interpretation of virtually all distress types, including fine (subpixel) transverse cracks on continuously reinforced concrete pavement (CRCP), and low-severity alligator cracking. These images had a nominal resolution of 1/8 in. For this reason, it is felt that video data collected with systems using two video cameras, one covering each wheelpath, will collect video data with adequate resolution for human interpretation. This assumes that adequate control of exposure time is used to limit blurring and that ambient illumination does not obscure the cracks.

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Although human interpretation of subpixel cracks is achievable, the comparable capability of a video image processing system has yet to be shown reliable. For this reason, higher resolution video images are warranted to make the detection of such fine cracks (e.g., as are common in low-severity D-cracking) reliable. One such strategy to accomplish this might be to add two additional cameras that would provide video images from a much smaller area centered about each wheelpath. In this way, nominal resolution image data from the entire lane width would be augmented with high-resolution images of the wheelpath necessary for reliable detection of fine cracks.

It is anticipated that such video image acquisition systems will ultimately incorporate controlled lighting, as is used by PASCO and PCES image acquisition systems. Such an improvement will reduce the variability in the collected images, resulting from changes in the level and direction of ambient illumination and artifacts, such as shadows from overhead structures and adjacent vehicles. Although human interpretation may be very tolerant of such undesired variability, "teaching" a computer to tolerate such artifacts is a very challenging task.

Because it is unlikely that one single form of acquired video data will meet all needs for pavement distress surveys, it is interesting to consider what the ideal video image acquisition system should look like. It is the researchers view that a system that would meet the most diverse needs would incorporate a high resolution sensor with a linear array of 4,000 to 8,000 pixels spanning the 12-ft lane width. Such linear arrays (albeit of lower resolution) are currently used in PDI-1 of Roadman-PCES. As the image acquisition system moves down the road, it accumulates a series of lines of data, each corresponding to one line in a continuous strip image of the pavement. This series of lines could then be reduced on-line to a variety of images, with different resolution (1/4-, 1/8-, 1/16-, and 1/32-in. pixel size) and coverage (entire lane width, left half of lane, right wheel path, etc.). After scan conversion, the selected set of video data could be stored on one or more video tapes or analog optical disk. In this way, a single image acquisition system could accommodate the needs of every state highway agency.

Although relatively costly, if high resolution image data are desired across the entire lane width, there currently is no substitute for film recording (such as offered by PASCO). What is needed is a convenient way to get the images from the film into the video image processing system. A film scanner that would "lift" digital images from the film would provide the best means of accomplishing this. Such film scanners are commonly used for microfilm readers. However, in this application the film scanner needs to output grey-scale images, rather than the bitonal images generated by microfilm readers. There is no technological barrier in developing such a device. The needed film transport systems are already in use in microfilm readers. However, a different type of line scan sensor must be incorporated to enable the film scanner to capture greyscale digital data. With such a film scanner the video image processing system would be presented high resolution image data of the entire swath of pavement surface a single raster line at a time and process the image data in the same manner. The high resolution image data derived from the film scanner would also allow a visual interpreter to scan down the film in a continuous manner at variable rates, thereby permitting the accumulation of visual survey data. In this way, the image of the pavement surface stored on 35-mm film can be interpreted by either a manual reviewer or a video image processing system.

Potential for Automating Pavement Distress Surveys

NCHRP Project 1-27 has demonstrated the fundamental capabilities of a video image processing system for determining distress type, severity, and extent. The developed system was shown to produce reasonable extent estimates for the following distress types: (1) PCC pavements (longitudinal cracking, transverse cracking, joint deterioration); (2) asphalt-surfaced pavements (longitudinal cracking, transverse cracking, alligator/block cracking).

On PCC pavements, tining of the surface posed the largest problem to system performance. The effects of tining would be reduced by less directional lighting, albeit with some reduction of the visibility of features running transverse to the lighting. The effect of tining could be further suppressed by an algorithm which would detect all surface features that appear straight, collinear, and parallel, and "cull" them from further consideration.

As expected, asphalt-surfaced pavements are more challenging than PCC pavements, primarily because of the reduced contrast between the distress and its neighboring background, but also because of the way such distresses tend to blend with the matrix of the aggregate at the surface. This tends to make cracks detected on asphalt-surface pavements fragment into many smaller individual cracks. The approach developed in this project took this into account during the course of the design of the algorithms for the video image processing system. The approach taken in the video image processing system does tolerate much of the fragmentation found on asphalt-surfaced pavements. However, it seems that further improvements in performance would be achieved by making the system more locally adaptive to the local conditions of the pavement. This might be accomplished by gauging the apparent surface texture of the pavement and adapting parameters of the algorithms to best suit the current surface characteristics.

Clearly, there are more surface distresses of interest for pavement surface distress surveys than the current project has been able to tackle. The manual prepared for SHRP LTPP studies enumerates 16 distress types for jointed PCC, 15 distress types on asphalt-surfaced pavements, and 14 distress types for CRCP. The video image processing system which can recognize all or most of these distresses will require further sophistication, particularly to detect those distresses, which evidence themselves as rather subtle changes in the surface characteristics.

It is, for this reason, that the hardware for the video image processing system must permit extensibility. Within such an extensible system, the current approach used for detecting cracking and joints can be viewed as one toolset for filtering out cracking and joints. Another toolset could be added to filter out tining, thereby eliminating it from further consideration. Additional toolsets could be added to sift out surface defects such as D-cracking and corner breaks for quantification. There will definitely be some overlap between the techniques used to detect and quantify further distress types. However, there will also be some unique processing that is specifically tailored to single distress types. In this way, the video image processing system will evolve to a series of processing techniques that can span the vast majority of distress types. The issue in reducing machine vision technology to practice for evaluating pavement surface distress is the development and testing of the image processing and pattern recognition techniques. Hardware capabilities are there to implement almost all that a judicious designer can envision. However, the developer does need to focus on processing techniques that are reachable with the foreseeable evolution of computer technology. Still, there is a certain degree of circularity to the path to mature the technology. *In order to develop confidence in the methods, the development and testing must move from the processing of individual images to the processing of many lane miles of pavement.* This, in turn, requires more sophisticated processing hardware to adequately accomplish such evaluations.

It is difficult, if not impossible, to extrapolate research findings derived from a handful of video images to predict performance on a hundred images, let alone thousands of lane miles of video data. Even the relatively large sample processed during this project (3,000 images covering more than a lane mile) is dwarfed by the several thousand lane miles that fall under the jurisdiction of most state highway agencies. Nonetheless, the project has made a significant step toward transferring the technology to application, by assessing performance on contiguous sections of pavement (each typically comprising about a hundred frames of video data).

Research will continue to play the role of advancing new techniques to the point where they merit increasingly more extensive testing. However, just as critical to the advancement of the technology is the extensive testing of existing techniques. It seems that state highway agencies are the logical place for such extensive evaluation relative to application of the technology.

NOTE: The final report was authored by Dr. Richard A. Fundakowski, the principal investigator, along with Messrs. Robert K. Graber and Robert C. Fitch, all of Triple Vision, Inc.; and Dr. Eugene L. Skok and Mr. Erland O. Lukanen of Braun Intertec Pavement, Inc. The report is available, on a loan basis, from the Transportation Research Board, Business Office, 2101 Constitution Avenue, N.W., Washington, D.C. 20418. Also available are the computer programs that comprise the Pavement Video Inspection System (PVIS) and the video disk of the 30 test sections used for validation purposes and fully described in Appendix B of the final report.