Low-Cost Video Image Processing System for Evaluating Pavement Surface Distress

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Most pavement condition surveys use rating systems in which pavement distress is measured by type, extent, and severity. Rating either bituminous or portland cement concrete pavements by the pavement condition rating (PCR) or similar systems is tedious and time-consuming. In most instances, distress measurement is subjective, which affects the actual rating. Improved data collection and data processing methods are thus needed to expedite pavement evaluation that can be used as input in pavement management systems. Recent advances in computer technology now permit the identification and quantification of distress types that can be measured by width, length, or area by automatic analyses of images captured by a microcomputer from video or film recordings. The development of a low-cost system for video image pavement distress analysis is described; the system allows the identification, classification, and quantification of commonly occurring pavement distress types in terms of severity and extent. Once pavement distress is identified, quantified, and classified, the system can be combined with rating procedures (such as PCR) to obtain a quantitative measure of pavement condition. Hardware and software characteristics of the system are described in detail. Diagrams showing the connection of system components and procedural steps leading to the calculation of a pavement rating are also included. Distress identification and classification is currently limited to distress types that can be quantified by width, length, geometry, or area covered by the distress.

Pavement management systems (PMSs) have been essential means of identifying road sections in need of maintenance or repair to allocate funds so that a maximum benefit/cost ratio can be achieved. Rating systems constitute fundamental inputs to a PMS. State transportation officials use these systems to quantify roadway performance with time. Rating systems are based on visual inspections in which pavement distress is measured by type, extent, and severity. The time-consuming procedure is normally subjective and nonrepetitive, thus affecting the actual rating.

The automation of pavement condition data collection and processing methods has become an important study topic. Some research and transportation agencies have made considerable progress in image analysis to obtain a pavement rating based on surface distress, but the system is still in the process of development.

Work by Baker et al. (1), Acosta (2), and Acosta et al. (3) indicates not only that automated video image pavement distress analysis is possible but that it is within the reach of implementation with currently available equipment and within a short time.

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This paper describes the development of a low-cost system for video image pavement distress analysis that allows several commonly occurring pavement distress types to be identified, classified, and quantified in terms of severity and extent. Once this has been done, the system can be combined with rating procedures—such as the pavement condition rating (4)—to obtain a quantitative measure of pavement condition.

Hardware and software characteristics of the system are described in detail. Diagrams showing the connection of system components and procedural steps leading to the calculation of a pavement rating are included. Distress identification and classification are limited to types that can be quantified by width, length, geometry, or area covered by the distress. The system is capable of identifying, quantifying, and classifying distress within each of the most common types of pavements, namely, flexible, jointed concrete, and composite pavements.

Software development included provisions to allow the future consideration of additional distress types as specified in the PCR manual (4).

BACKGROUND

Computer-based image analysis was originally developed as a powerful tool in the medical sciences (5,6). Since then its use has been extended to a variety of disciplines, as shown by several texts on digital image processing (7–10).

General-purpose software currently available can perform image enhancements (11); however, identifying features or objects in an image is a much more difficult task. Quantifying images requires the use of specialized software that identifies features of interest and extracts geometric measurements from the digital image. Specific problem-dependent software must be developed to extract features for particular applications (12,13). Combinations of algorithm-based programs (for image enhancement) and rule-based programs (for object extraction) have been shown to be effective in feature extraction problems (14,15).

Recently, Fukuhara et al. (16) developed an automatic pavement distress survey system using a combination of a laser scanner, a photomultiplier tube, and a video camera connected to a signal processor. Rutting and longitudinal profile data are processed in real time and stored in a magnetic tape data bank. Cracking data is analyzed from the playback of recorded images. However, using specialized equipment may limit the system's broad application for pavement distress analysis.

GENERAL CONCEPT

The development of a video image pavement distress analysis system follows from the authors' work on crack and inclusion detection on metal and ceramic substrates. The analysis of an image proceeds in five steps: image digitizing and deblurring, image segmentation, clustering, feature extraction, and cluster classification. Image digitization is effected with a low-cost commercially available image capturing board residing in a microcomputer. Initial image segmentation is done by adaptive techniques using convolution, histogram, and primal sketch methods, among others (17–20). Damaged areas and other features within the pavement highlighted by segmentation are clustered to form objects (21). Calculation of geometric properties of these areas and features such as area, radius of gyration, aspect ratio, and others is required, along with the application of characteristic rules, to classify them as pavement distress, pavement feature, or unknown object (litter, debris, etc.). Pavement rating follows applying the dimensional guidelines specified in the rating manual.

HARDWARE CONFIGURATION

Most components of the video image analysis system for pavement distress are commercially available. This allows the assembly of a relatively low cost and reliable system, which may encourage transportation agencies and local governments to automate their pavement evaluations.

Video image recording and analysis are conducted separately, because computer storage space is limited and because data processing takes longer than data recording. This approach contributes to the versatility of the system and eliminates the need of a computer in the data collection vehicle.

A complete data acquisition and analysis system is estimated to cost about $30,000. The recording equipment includes a super VHS format video camera with mounting frame and adequate lens, depth measurement instruments, and their interfaces with video recording equipment. The video image analysis system includes a super VHS tape player, an image capturing board, a microcomputer CPU (or workstation), and monitors. The cost of a vehicle (preferably a van) to house the equipment should be added to the estimate.

Video Recording Equipment

Separating the video recording and analysis tasks simplifies image collection and reduces the possibility of equipment damage, because most of the equipment is operated in an office setting.

The video recording vehicle assembled at Case Western Reserve University consists of a pickup truck and a carry-on air-conditioned camper containing a 110-VDC power plant. A steel frame projects 7 ft from the rear of the camper to let the video recording camera be mounted perpendicular to the pavement without visual obstruction by the vehicle. The height of the steel frame is adjustable, allowing image recording at 5 to 8 ft from the pavement surface. The camera height is varied to provide the required pavement section width coverage and image resolution. Suitable video images have been obtained at vehicle speeds of up to 55 mph. Lighting fixtures are mounted on the frame to allow image recording at night. Shadows from other vehicles, the recording vehicle, roadside furniture, trees, and overpasses are avoided during nighttime recording. This simplifies and expedites further image analyses.

A super VHS format video camera with variable shutter speed of up to $1/1,000$ sec provides images of adequate resolution (up to 240 lines/frame) for pavement distress analysis. Individual frames are recorded every $1/60$ sec to provide continuous coverage of the selected pavement section.

A 58-mm perispheric video lens was adapted to the super VHS camera to provide a distortion-free area approximately three times the size of the area obtained by a conventional lens. The perispheric lens provides focused full-lane coverage within the height ranges of the mounting frame.

Images are recorded directly on a super VHS cassette tape, although at times the camera video and sound outputs are connected to an optional on-board super VHS videocassette recorder for backup. A microphone in the vehicle cabin allows the driver to record comments directly on the videotape. These comments about visual observations are used for future reference; they include starting log mile or continuing stationing, changes in pavement features, road and lighting conditions, and other items of interest.

Video Image Analysis Equipment

The development of a video image analysis system for pavement distress includes special requirements to obtain a system capable of

- Differentiating between cracks and joints in rigid pavements;
- Covering pavement sections a full lane wide and between 250 and 1,000 ft long;
- Processing images obtained at more than 45 mph;
- Identifying type, severity, and extent of distress; and
- Evaluating either rigid, flexible, or composite pavements.

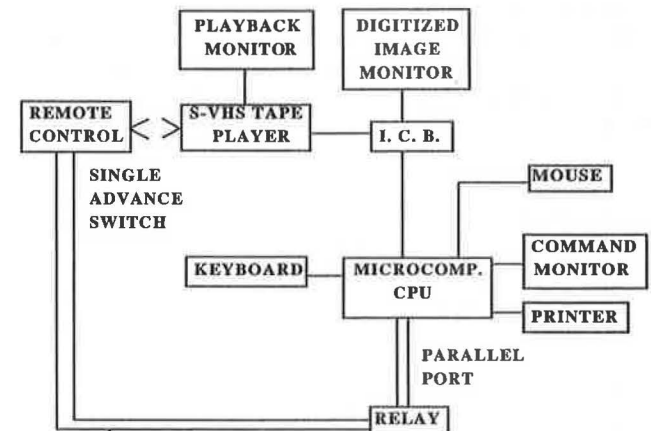Functional video image analysis equipment has been assembled following the configuration shown in Figure 1. The

FIGURE 1 Video image analysis system components (3).

characteristics of the principal system components are presented next.

Super VHS Tape Player

After trying several professional models, a consumer super VHS format tape player/recorder was found to be the most suitable for attaching to other system components. Besides having the super VHS format, the player is capable of accurate single-frame advance. This is important in image analysis, because real-time processing is impossible within cost constraints. A playback monitor connected to the tape player allows the review of images and comments recorded along the roadway to initialize image analysis at the desired pavement section.

Image Capturing Board

Communication between the tape player and the CPU is effected through an image capturing board. Image processing is initiated with the playback of tapes at the beginning of the desired pavement section. But before an image can be captured, the image capturing board must be synchronized with the video signal from the tape player. Synchronization is achieved through commands issued to the image capturing board in the developed software. The image capturing board used in the system along with software library commands (*11*) enables the control of up to four boards (512 × 512, 8-bit deep frame buffer) within one system. The image capturing board is connected to a video monitor to permit viewing of digitized and processed images.

Microcomputer CPU

Currently, an MS-DOS 386-compatible microcomputer with a 16-MHz clock speed is used for image analysis control and processing. The tower-model microcomputer contains hard disk and floppy drives, a math coprocessor, 1MB RAM, and serial and parallel ports; it is attached to peripherals such as a command/graphics monitor, printer, mouse, and keyboard. The image capturing board requires two full-length 16-bit expansion slots on the microcomputer motherboard.

Relay

A 5-VDC relay is used to control single-frame advance by the videotape player remote control through timely software commands issued to the microcomputer parallel port. The parallel port generates a DC voltage signal after its activation with the software commands to close the circuit on the single-frame advance button of the remote control. Up to eight functions can be used through the parallel port without an additional interface board.

Image Resolution

Advanced high-resolution display monitors have a maximum resolution of 1024 × 1024 pixels (512 × 480 is the current standard), which mandates the width of visual images to obtain the minimum desired crack width identification of ⅛ in. If one pixel represents a minimum crack width, then a maximum width of 128 in. (10.67 ft) of roadway can be displayed on the advanced monitor to obtain the desired crack width resolution.

SOFTWARE DEVELOPMENT

This section describes general image analysis software and its five principal steps: image digitizing and deblurring, image segmentation, clustering, feature extraction, and cluster classification. Important topics concerning the developed computer program, PAVEDIST (PAVEment DISTress), are addressed in order to clarify some of its procedural steps; for more details, refer to the work by Acosta (*2*).

Background and General Description of Image Processing System

The development of a video image pavement distress analysis system follows from the work performed by Braun et al. in the nondestructive testing of ball bearings through imaging techniques conducted for the National Aeronautics and Space Administration (*22*). This research dealt in particular with the inspection of a rolling bearing component to measure the distribution, size, and shape of carbide particles (which act as crack initiation) on or near the surface of the bearing component. From this information, the predicted service life can be determined.

The effectiveness of the algorithms developed for extracting cracks and other damage from metals and composites in the identification of concrete pavement distress and further rating of a pavement section has been shown through the analysis of many video images. However, the algorithms relating to image segmentation revealed poor results in the analysis of asphalt concrete pavements, because this type of pavement yields textured and nonhomogeneous background images. The reasons for the unsatisfactory results will be addressed in further sections. Consequently, other techniques in image segmentation were studied and a new technique was developed.

A generalized flowchart of the image analysis software system is presented in Figure 2. Image analysis is initiated after the synchronization of the videotape player with the image capturing board. Scale definition before initiating the roadway survey is necessary if the distance between the camera and the road surface has changed. In practice the longitudinal and transverse length scales are recorded at the start of each tape.

PAVEDIST issues the command to advance a single frame through the parallel port, as explained. The image is captured by the board and stored in a two-dimensional array that coincides with the pixel position on the monitor. Values in the array represent the gray level on a scale between 0 (black) and 255 (white).

Before any clustering of pixels to define damaged zones, the original image is preprocessed to eliminate blurring that results from obtaining images at the high speeds of the recording vehicle. The deblurring process developed at Case Western Reserve University has been effective on images taken at speeds of up to 55 mph.
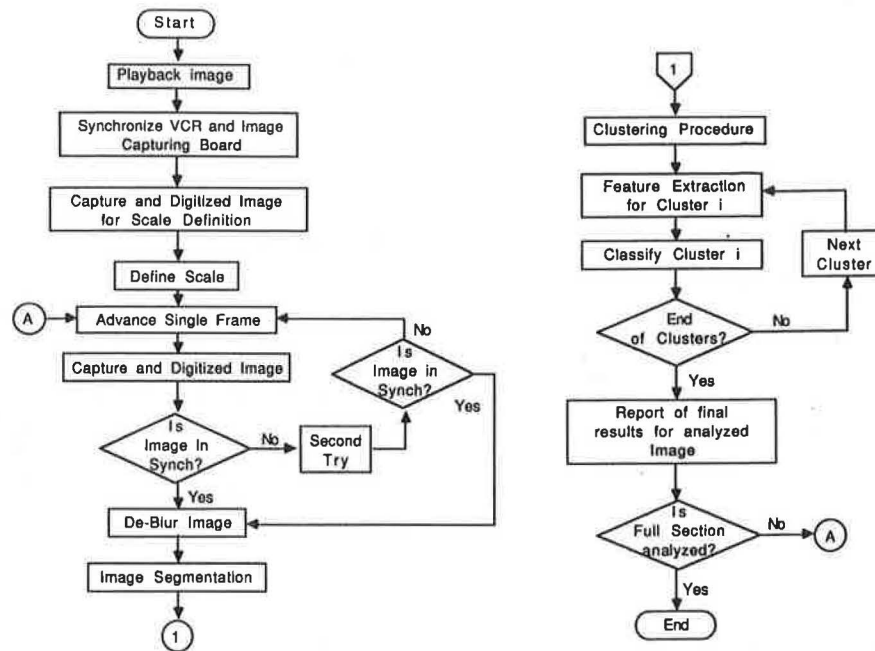
FIGURE 2 Image processing of pavement distress flowchart (3).

Statistical procedures are used to distinguish damaged zones from the background, for asphalt concrete pavements in particular. Once the image is segmented as background and foreground, adjacent pixels are clustered to outline damaged zones. Dimensional properties of each cluster are calculated, which will be useful in the further quantification of the type, severity, and extent of the pavement distress, according to the definitions in the PCR manual (4).

Image Digitizing and Deblurring

The image from the VCR player is digitized by means of the MVP-AT video digitizer and the IMAGER-AT MS-DOS software library (10). This software consists of routines that provide hardware controls for the MVP-AT digitizer such as frame buffer input and output, graphics, and imaging functions. The computer language directly supported by IMAGER-AT is Microsoft C.

The analog image from the VCR is digitized in a 512-×-480 array of pixels, each one stored in 1 byte of memory. Therefore, positions in the array can have values ranging from 0 (black) to 255 (white). The software digitizes the image following two steps: first the odd rows are captured (1, 3, 5, . . . , 479), then the even rows (0, 2, 4, . . . , 480). Because the film velocity in the VCR player is 60 frames/sec and because the two steps in the digitizing process take more than $\frac{1}{60}$ sec, the final captured image is composed by odd lines corresponding to the actual frame and by even lines belonging to the next one. Thus, the deblurring can easily be accomplished either by merging the odd rows of the next frame with the even rows of the actual image or just by taking the odd rows of the actual image and compressing them, as selected in the described system. Obviously, the odd-line extraction deblurring method changes the longitudinal scale; this must be taken into account for further analysis.

Image Segmentation

Different techniques in image segmentation were attempted (3), including

- Histogram thresholding (23),
- One- and two-dimensional entropy-based approaches (24),
- Edge detectors (25), and
- Vertical region segmentation (2,3).

The vertical region segmentation (VRS) method was developed to overcome the drawbacks encountered when using the first four techniques to segment asphalt concrete pavement images.

Bituminous pavement images present a gradual change of brightness in the transverse direction. Darker zones are easily identifiable on the wheel-track regions as the result of stains, wear, or rubber marks from tires. In addition, the mineral aggregate displays randomly distributed tones, therefore the image must be treated as a nonhomogeneous textured image.

As explained by Acosta (2) and Acosta et al. (3), the VRS method divides the image into narrow longitudinal sections so that each section can be analyzed separately. The gray-level histogram is obtained, and the gray-level average and the standard deviation are calculated taking into account only the gray levels with significant occurrences in the frequency distribution. Three zones are delimited: background (undamaged pavement), connective (transition between background and foreground), and foreground (pavement distress). The zones are delimited on the basis of the average, the standard deviation, and two constant parameters that depend on the texture pattern of the image itself. Figure 3 illustrates the boundary positions for each zone. The pixels are assigned to one of the three zones on the basis of their gray-level values.

A distressed asphalt concrete image is shown after the VRS method is applied in Figure 4. The resulting image identifies
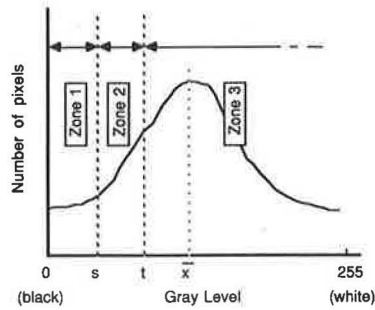
FIGURE 3 VRS zones (3).

clearly the distress from the background, the noise produced by strains and tire marks is no longer visible, and the effect of the gradual change in darkness is eliminated. These favorable aspects are the result of the introduction of the connective zone, the analysis of separate narrow vertical regions, and the use of the gray-level histogram in conjunction with statistical operandi [for more details refer to Acosta et al. (3)].

Clustering

The clustering procedure is done by linking all the adjacent foreground and connective pixels so that the cluster is sur-
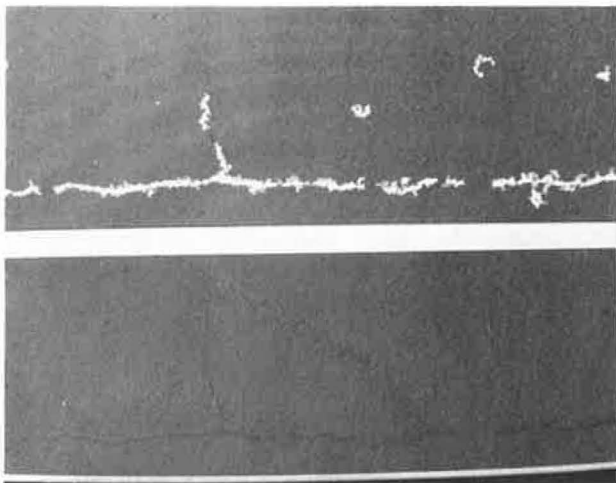

FIGURE 4 Asphalt concrete pavement image after VRS distresses are drawn in white (*top*); for comparison, digitized image is shown (*bottom*) (3).

rounded only by background pixels. A subroutine has been implemented to make this linking possible according to the following steps:

1. The image is scanned in a top-bottom and left-right pattern, seeking foreground or connective adjacent pixels whose coordinates are stored in a list corresponding to a particular cluster.

2. When adjacent pixels from different clusters are located, the clusters are merged.

3. All clusters with a number of pixels (foreground + connective) smaller than a minimum cluster size and clusters with foreground pixels less than a minimum value are deleted to eliminate clusters with sizes not relevant to the analysis.

Feature Extraction

A set of geometrical and statistical properties of a cluster is calculated by PAVEDIST for feature extraction. These features are used to identify a particular type of distress following a set of rules (rule-based system), as will be explained.

The total number of pixels is the sum of pixels from Zone 1 (foreground) and Zone 2 (connective); it is represented by n. The number of foreground pixels is represented by m. Transverse and longitudinal length are b and l.

The cluster is located in a bounding box with coordinates (x_{min}, y_{min}) and (x_{max}, y_{max}). Thus

$$b = x_{max} - x_{min} \tag{1}$$

$$l = y_{max} - y_{min} \tag{2}$$

The x-coordinate variation, x_{var}, is defined as

$$x_{var} = \sum \frac{x^2}{n} - (x_{cg})^2 \tag{3}$$

The y-coordinate variance, y_{var}, is defined as

$$y_{var} = \sum \frac{y^2}{n} - (y_{cg})^2 \tag{4}$$

where (x_{cg}, y_{cg}) are coordinates of center of gravity calculated as follows:

$$x_{cg} = \frac{\sum x}{n} \tag{5}$$

$$y_{cg} = \frac{\sum y}{n} \tag{6}$$

and

(x,y) = coordinates of each pixel.

The gray-level mean, $\overline{Z}$, is defined as

$$\overline{Z} = \frac{\sum z}{n} \tag{7}$$

where Z is $f(x, y)$ or gray-level of the pixel with coordinates (x, y).

The gray-level variation, Z_{var}, is defined as

$$Z_{var} = \frac{\sum Z^2}{n} - (\overline{Z})^2 \qquad (8)$$

Inertia in the x- and the y-direction, I_x and I_y, are the inertias about axes parallel to the original axes with origin at the center of gravity of the cluster. They are defined as

$$I_x = \sum x^2 - x_{cg}(\sum x) \qquad (9)$$

$$I_y = \sum y^2 - y_{cg}(\sum y) \qquad (10)$$

The product moment of inertia, I_{xy}, is defined as

$$I_{xy} = \sum xy - x_{cg}(\sum y) \qquad (11)$$

Principle moments of inertia, I_{max} and I_{min}, are defined as

$$I_{max} = \frac{I_x + I_y}{2} + \frac{1}{2}[(I_x - I_y)^2 + 4(I_{xy})^2]^{1/2} \qquad (12)$$

$$I_{min} = \frac{I_x + I_y}{2} - \frac{1}{2}[(I_x - I_y)^2 + 4(I_{xy})^2]^{1/2} \qquad (13)$$

The angle of principal axes of inertia, β, is the angle with respect to the horizontal. It is calculated from

$$\tan 2\beta = \frac{2I_{xy}}{I_y - I_x} \qquad (14)$$

The inertia ratio, τ, is defined as

$$\tau = \frac{I_{min}}{I_{max}} \qquad (15)$$

Each distress is isolated by a boundary box that encloses it. The ratio between the transverse and longitudinal dimensions of the box is the shape factor. Cluster length is the length of a straight line passing through the center of gravity of the cluster following the direction of the angle of principal axes of inertia and limited by the bounding box that encloses the cluster. Cluster width is the average width of the cluster calculated with the ratio between the area and the cluster length.

These features are calculated twice by means of a subroutine. First, the features are extracted from the unjointed clusters; after they are brought together, new features are measured from the joined objects. The cluster classification is performed on the basis of the new features.

PAVEDIST compares all the clusters by pairs and joins two clusters if they satisfy the following conditions:

- The clusters are close enough. The physical meaning of "close enough" depends on the scale of the image, that is, the length represented by a pixel.
- The angles of the principal axes of inertia of the clusters are similar (a tolerance is given); furthermore, these angles must be similar to the angle formed by a straight line connecting the centers of gravity of the clusters.

If the objects satisfy the conditions, they are brought together and the new object is compared with all the others. The procedure is repeated until no more cluster connections are possible.

Cluster Classification

A rule-based classification approach was developed, taking into account two distress types: transverse and longitudinal cracking. Typical ranges of values for the features extracted for transverse and longitudinal cracking were heuristically determined. A subroutine was implemented with decision rules that compare the features extracted from the object; the subroutine classifies it as transverse cracking, longitudinal cracking, or unidentified distress type. The accuracy of this subroutine is close to 90 percent, and most misclassifications arise from objects with feature similar to the groups analyzed— objects that need more features to be correctly classified.

Finally, PAVEDIST draws the clusters belonging to each particular group in the digitized image monitor and total properties are obtained to be used as input for the future PCR calculation.

PCR Routine

The PCR routine was implemented following the guidelines in the PCR manual (4) to calculate the PCR using data stored in an output file from PAVEDIST.

The data file must an identification of the highway analyzed and the pavement width (in feet). Each analyzed section must have data for its beginning and ending (in miles) and a set of data for which each datum must be conformed by:

- Distress Code: code assigned to the distress type. A list of distress codes is included in Table 1.
- Severity-Property-1 (sevp1) and Severity-Property-2 (sevp2): numerical values representing the severity level (low, medium, or high) of the distress type.
- Extent-Property (extp): numerical value representing the extent level (occasional, frequent, or extensive) of the distress type.

Severity-Property-1 (qualitative), Severity-Property-2 (quantitative), and Extent-Property are based on the definitions for severity and extent given in the PCR manual (4) for each distress type; they are also summarized in Table 2.

The PCR values calculated for the analyzed sections are stored in an output file that, like the input file, contains an identification of the highway analyzed and the pavement width (in feet). Each analyzed section must have the beginning and ending of the section (in miles) and a PCR value.

The weights for the distress types taken from the PCR manual are read from a data file.

SUMMARY AND CONCLUSIONS

An initial system for video image pavement distress analysis that allows the identification and classification of common types of structural pavement distress was developed. Signif-

TABLE 1 DISTRESS CODES

Distress Type	Type of Pavement		
	Asphalt Concrete	Composite	Port.Cem Concrete
Block and Transverse Cracking	1101	2101	3101
Longitudinal Joint Cracking	1102	2102	3102
Wheel Track Cracking	1103		
Raveling	1104	2104	
Random Cracking	1105		
Edge Cracking	1106		
Potholes	1107		
Patching	1108	2108	3108
Surface Deterioration		2109	3109
Popouts			3110
Pumping		2111	3111
Bleeding	1112	2112	
Faulting			3113
Settlements	1114	2114	3114
Joint Spalling			3115
Joint Sealant Damage	1116	2116	3116
Pressure Damage		2117	3117
Corner Breaks			3118
Rutting	1119	2119	
Corrugations	1120	2120	
Shattered Slab		2121	
Unidentified	1000	2000	3000
Debris	1001	2001	3001
Manhole Covers	1002	1003	1004
Shadows	1003	2003	3003
Noise	1004	2004	3004

TABLE 2 PCR DISTRESS DEFINITIONS FOR SEVERITY AND EXTENT WEIGHTS

Dist.	Severity Weights			Extent Weights		
Code	Low	Medium	High	Occas.	Freq.	Extens.
1101	CW<1/8"	1/8"-1"	>1"	PSL<20%	20%-50%	>50%
1102	Single CW<1/8"	Mult. 1/8"-1"	Mult. >1"	PSL<20%	20%-50%	>50%
1103	Single CW<1/8"	Mult. 1/8"-1/4"	Exten. >1/4"	PSL<20%	20%-50%	>50%
1104	Little	Moderate	Severe	PA<20%	20%-50%	>50%
1105	CW<1/8"	1/8"-1"	>1"	PSL<20%	20%-50%	>50%
1106	no break CW<1/4"	some spall. 1/8"-1"	mult. crack. >1"	PSL<20%	20%-50%	>50%
1107	Di<6"or (Di>6"& De<1")	Di>6"& De:1-2"	Di>6"& De>2"	PSL<20%	20%-50%	>50%
1108	Fair ride	Poor ride	Bad ride	PSL<10%	10%-30%	>30%
1112	Noticeable	Noticeable	Very notic.	PA<10%	10%-30%	>30%
1114	Fair ride	Poor ride	Bad ride	<1/mile	2-4/mi.	>4/mi.
1116				PSL<20%	20%-50%	>50%
1119	De<1/4"	1/4"-1"	>1"	PSL<20%	20%-50%	>50%
1120	Fair ride	Poor ride	Bad ride	PSL<10%	10%-30%	>30%
2101	CW<1/8"	1/8"-1"	>1"	CS>15'	10'-15'	<10'
2102	CW<1/8"	1/8"-1"	>1"	<50'/ST	50'-100'	>100'
2104	Little	Moderate	Severe	PA<20%	20%-50%	>50%
2108	Fair ride	Poor ride	Bad ride	PSL<10%	10%-30%	>30%
2109	De<1"& A<1 yr²	(De<1"& A>1 yr²) or (De>1"& A<1yr²)	De>1"& A>1 yr²	PSL<20%	20%-50%	>50%
2111	Stains around cracks	Stains around cracks	Fault.	PSL<10%	10%-25%	>25%

TABLE 2 (*continued*)

Dist. Code	Severity Weights			Extent Weights		
	Low	Medium	High	Occas.	Freq.	Extens.
2112	Noti-ceable	Noti-ceable	Very notic.	PA<10%	10%-30%	>30%
2114	Fair ride	Poor ride	Bad ride	<1/mile	2-4/mi.	>4/mi.
2116				PSL<20%	20%-50%	>50%
2117	De<1/2"	1/2"-1"	>1"	PSL<20%	20%-50%	>50%
2119	De<1/4"	1/4"-1"	>1"	PSL<20%	20%-50%	>50%
2120	Fair ride	Poor ride	Bad ride	PSL<10%	10%-30%	>30%
2121	Fair ride	Poor ride	Bad ride	<2/mile	2-5/mi.	>5/mi.
	CW<1/8"	1/8"-1"	>1"			
3101	CW<1/4"	1/4"-1"	>1"	CS>15'	10'-15'	<10'
3102	CW<1/4"	1/4"-1"	>1"	PA<5%	5%-20%	>20%
3108	Light	Moder.	Severe	PA<5%	5%-20%	>20%
3109	De<1/4"	1/4"-3/4"	>3/4"	PA<20%	20%-50%	>50%
3110				PSL<20%	20%-50%	>50%
3111	Stains around cracks	Stains around cracks	Faulting	PSL<10%	10%-25%	>25%
3113	De<1/4"	1/4"-1/2"	>1/2"	PSL<20%	20%-50%	>50%
3114	Fair ride	Poor ride	Bad ride	<1/mile	2-4/mi.	>4/mi.
3115	CW<2""	2"-4"	>4"	PSL<20%	20%-50%	>50%
3116				PSL<20%	20%-50%	>50%
3117				<1/mile	1-3/mi.	>3/mi.
3118	CW<1/4"	1/4"-1"	>1"	<1/mile	1-3/mi.	>3/mi.

Abbreviations:

CW:	Crack width
PSL:	% of occurrence in section length
PA:	% of occurrence in section area
Di:	Diameter
De:	Depth
CS:	Crack spacing
ST:	Station
A:	Area

icant differences in the image segmentation of asphalt concrete and portland cement concrete images and classification approaches were found from this work.

Thresholding techniques based on either one- or two-dimensional histograms applied to asphalt concrete pavement image segmentation are not adequate. An asphalt concrete pavement image is composed of mineral aggregate with a wide range of gray tones embedded in a bituminous mixture with dark gray intensity. Moreover, the image displays a gradual change in darkness along the transverse direction because of stains and rubber tire marks. Consequently, the foreground and background can have similar gray tones, and a threshold value is unable to separate the foreground from the background pixels.

Edge detector methods in asphalt concrete pavement image segmentation do not reproduce a fair distress border or an accurate segmentation because the perimeter of the defects in discontinuous and the aggregate particles can be mixed up with the actual distress types.

The VRS method (2,3) constitutes an adequate and accurate technique in asphalt concrete pavement image analysis. The connective zone considerably improves the image segmentation results, and the analysis of separate vertical zones takes into account the influence of the gradual change in darkness along the transverse direction. Although the method was implemented mainly for asphalt concrete pavement images, it can successfully be used for portland cement concrete pavement images.

The accuracy achieved with the rule-based classification approach is close to 90 percent, and the misclassifications result from objects with features similar to the groups analyzed. They can be identified by taking into account more parameters in the decision rules implemented in the classification procedure.

The results obtained with the initial implementation of the low-cost system for video image pavement distress recording and analysis proved that an accurate and reliable quantitative measurement of the pavement condition can be calculated. Furthermore, the system eliminates the subjectivity inherent in manual pavement distress analysis.

Distress classification including severity and extent level is currently limited to distress types that can be quantified by width, length, geometry, or area covered by the distress. The system is designed to consider distress types requiring depth measurements once proper measuring techniques are developed.

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