

ARIATM: An Operating System of Pavement Distress Diagnosis by Image Processing

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Digital image processing and pattern recognition from a video log of pavement surface distress is accomplished by initializing the image processing board within an IBM-PC (or compatible). Software is used to set all image processing registers to zero or a default value, which digitizes values for each color (0 to 255), and sets an image processing board to continuously display signal readings from video log tape. The video signal is received by the image processing board and displayed on an image monitor. A pixel can represent 256 possible shades of gray, with 0 representing black, 256 representing white. The object of image processing is to enhance pavement surface distress (changing it to white) while diminishing the nondistress area (changing it to black). Pavement surface distress is distinguished by using one of several types of distress (crack) enhancement filters. For crack recognition, multiplication filters are useful, but multiplication filters cannot recognize crack pattern or classify type of cracking. Directional filters are used to classify cracking by splitting the image into horizontal and vertical components. The extent of cracking or crack width can also be determined by directional filters. Once the right filter value is selected, crack size and length are validated. The ARIATM image processing technology is accurate, consistent, and reliable, and may be used on any type of concrete or asphalt pavement.

Automated digital distress analysis was a program undertaken by MHM Associates, Inc., in 1985 to complement its pavement video logging service. Digital image processing and pattern recognition techniques from video images was expected to enable identifying and quantifying the main types of pavement deterioration. The positive results obtained in 1986 encouraged the firm to finance the automated road image analyzer (ARIATM) project—which was to provide a totally automated pavement distress data collection method for pavement management.

PRINCIPLES AND FUNCTIONS OF THE SYSTEM

Data Acquisition

ARIATM is an off-line system that uses images of the road surface for analysis purposes. The videolog produced by the specially equipped ARIATM van provides the necessary reference. This procedure is the only means of data collection used by MHM Associates. However, the methods and algorithms are adaptable to other forms of data acquisition provided the images offer comparable definition and contrast to

those of the images from the ARIATM videolog. The ARIATM van uses the following equipment for videologging of pavement surface and right-of-way.

1. Vehicle (Chevrolet van).
2. Distance measuring instrument (DMI) with a transmission-driven sensor. The DMI is superimposed on the videotape and the software is capable of matching each captured image with its respective DMI (which is the distance from the beginning of the section being taped).
3. Video Recording Equipment
 - a. Pavement Video Camera. This camera, which is used to videotape the pavement, can be set up to look straight down or at an angle to record the pavement surface.
 - b. Reference camera. This camera, which videotapes a view from the windshield or the right-of-way view, is pointed directly out the windshield at the horizon. The main purpose of this camera is to collect data on roadside objects within the right-of-way for future reference.
 - c. Superimposer. The superimposer superimposes the reference camera, DMI, and other header information on the video.
 - d. VCR. A four-head VCR records the information being videologged.
 - e. Cables, clamps, brackets, and braces. These are hardware necessary to mount the cameras.
 - f. Playback monitors. These are used to view what each camera is recording.

Videolog System Specifications

The ARIATM van currently operates and processes video signals on the basis of the following system or format:

The videotape system operates within an EIA standard video signal system based on 525 lines at 60 Hz, using the National Television Standards for Communication (NTSC) color signal. The advance speeds of the high-density tapes are either $1\frac{5}{16}$ in./sec (33.35 mm/sec) or $\frac{7}{16}$ in./sec (11.12 mm/sec); tape width is $\frac{1}{2}$ in. (12.27 mm); format is VHS. The CCD camera operates with 574 horizontal \times 499 vertical picture elements (pixels), in a scanning system that performs scanning of the 525 lines at 30 frames per second, providing a resolution of 380 lines from top to bottom of the frame. The video output level is 1.0 volt peak-to-peak for the NTSC composite signal at 75 ohms.

Remote Workstation Batch Mode Processing Equipment

In order to process video images through a remote computer system, video images need to be converted into digital images. This process of converting video images into digital images is done at a remote workstation by batch mode with ARIA™ software. Images can be processed any time of the day with or without the presence of a technician. However, an attendant is required if the playback is set to a single-frame advance mode because the VCR automatically shuts off after 5 min of play to preserve the video heads. When the video is played back at normal speed, a technician is not required, and the computer can process an entire 2-hr videotape from the VCR.

The computer, which operates on 120 volts ac at 60 Hz, is an IBM Personal Computer or IBM-compatible computer containing an 80386 microprocessor. It includes a VGA monitor with Video 7 V-RAM VGA adapter and 512-kb RAM. The image-processing hardware includes an NTSC converter that converts the NTSC signal from the VCR to red, green, blue, and synchronization signals for the image processor board, which digitizes the color image recorded in the videolog tape into gray values ranging from 0 to 255. The Sony image monitor displays what is in the memory of the image processor board. There are 80 Mb of hard disk, and the printer is an Epson nine-pin matrix printer. The video recording equipment consists of a four-head VCR and a playback monitor.

The languages of processing are assembly language and BASIC; the operating system is Microsoft MS-DOS 4.01.

THE ANALYSIS PERFORMED BY THE SYSTEM

The ARIA™ system can recognize and quantify the following types of pavement surface defect:

1. Alligator cracks;
2. Longitudinal cracks (single or multiple, sealed or not sealed); and
3. Lateral or transverse cracks (single or multiple, sealed or not sealed).

For each of these defects, the system quantifies the extent of the defect by distress density and provides precise information about the position or location of the distress in relation to a beginning reference. For each type of distress, the ARIA™ software detects and identifies the cracking pattern from each frame of video as digitized and analyzed by microcomputer. The minimum size of a detectable crack is $\frac{1}{16}$ to $\frac{1}{8}$ in. (1.6 to 3.1 mm). The software is capable of producing a data base that automatically identifies the location of distress as the computer reads the DMI from the digitized video frame. It also computes statistical information such as mean, mode, and standard of deviation of distress density for number of frames sampled or analyzed. In addition, it provides distress density graphs and reporting capability for cost analysis.

PRINCIPLES OF SOFTWARE ANALYSIS

The first step in image processing on a PC is initializing the image processing board. Pavement surface representing $9 \times$

9 ft (2.74×2.74 m) can be analyzed by digitizing those frames for final diagnosis. In order to detect and identify distress or pavement defects, the following steps are necessary:

1. Initialize the image processing board,
2. Freeze an image for analysis,
3. Select the portion of the video frame to be analyzed for distress diagnosis,
4. Process the image for crack detection, and
5. Classify the distress.

Initialization of the Image Processing Board

The image processing board is initialized by executing several programs at the DOS prompt that accomplish the following objectives:

1. All image processing board registers are reset to 0 or a default value.
2. The value of 0 is digitized and assigned to color 0, and the value of 255 to color 255, and similarly for all numbers in between.
3. The image processing board is set to continuously display signal readings from the videolog tape.

Freezing an Image

Once the image is received from the converter and the board is initialized, the video signal received by the image processing board is displayed on the image monitor. When the frame has been frozen, the computer reads the desired lines out of the board's memory and gets the color values for each picture element on that line. Then the computer goes on to read the next line until the entire image to be analyzed is constructed in the PC memory.

The different ways an image can be processed with software are virtually unlimited, but there are some memory and time constraints. In a PC, memory is segmented. Each segment is 65,536 (256×256) bytes long. The image processing board can store frames $512 \times 512 \times 8$ (262,144 bytes) or $640 \times 480 \times 8$ (307,200 bytes) in the onboard memory. The image monitor contains 640 pixels in a row, and 480 pixels in a column. A pixel has eight bits (a binary digit, a 0 or a 1). A pixel represents 256 possible shades of gray (2×2 , 8 times), with zero representing black, 255 representing white, and numbers 1 through 254 representing lighter shades of gray.

Selection of Parts of Video For Distress Diagnosis

The upper portion of the videolog image frozen on the image monitor consists of header information such as road name, date of video, and distance measuring device readout. The lower portion of the video frame indicates the surface of pavement to be analyzed. The lower half of the video is selected for analysis by defining a starting and ending row and column of pixels (see Figure 1).

Processing Image For Crack Detection

The object of image processing is to enhance the distressed areas (changing it to white), while diminishing the nondis-

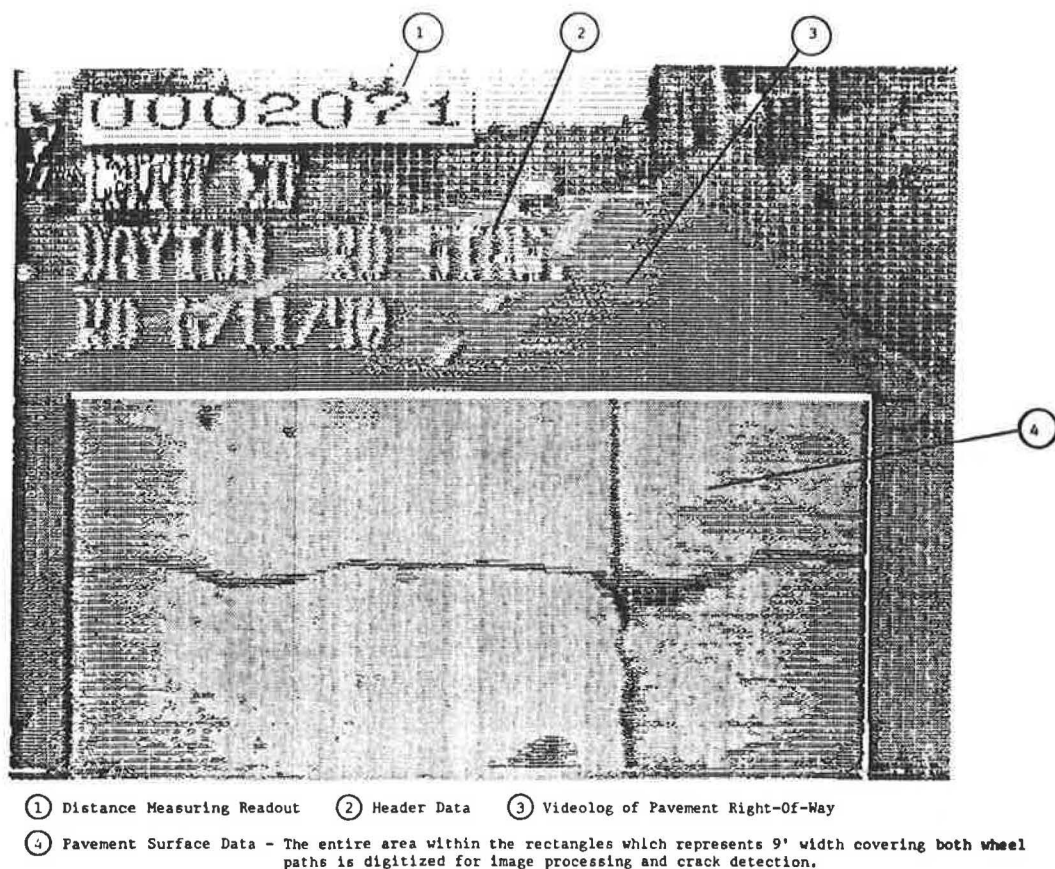


FIGURE 1 Computer printout of continuously acquired road right-of-way and pavement surface.

tressed areas (changing them to black). Each picture element in the area to be analyzed needs to be enhanced or reduced in value to easily distinguish the difference between the light and dark picture elements. Software algorithms have been developed by MHM Associates to accomplish this. For the purpose of this report, only one method of finding distress will be discussed. This method is classified as crack enhancement through multiplication filter (Figure 2).

After each pixel in the analysis area is enhanced and compared to its neighboring pixels, a decision logic based on threshold values retains or discards that pixel. If a pixel is retained by the decision logic, it is counted as a pixel representing a potential distress. Further software analysis groups the retained pixels as distress and nondistress pixels.

In this type of analysis, it is possible to calculate several thresholds of values to identify different types of deterioration by using a calibration menu. For example, threshold values can be set to identify cracking but not sealed cracks, and vice versa.

The multiplication filter, combined with threshold values, is used for general distress recognition. Although it can also

be used for crack classification, directional filters are more efficient for the identification of cracks such as longitudinal and lateral cracks. Figure 3 shows the steps used in detecting pavement surface cracking.

Directional Filter For Crack Classification

The object of crack classification is to find the amount of cracks and the extent and direction of each crack. In order to accomplish this, a directional filter (with threshold) must be created for general distress recognition. Directional filters are similar to multiplication filters, but instead of multiplying a picture element by a constant value, a constant value (a threshold value) is subtracted from the picture element values. Figure 4 shows a directional filter for determining and diagnosing cracks.

In Figure 4, the center pixel (the box marked CCCC), is compared with several pixels in the same column as itself, as well as several pixels in the same row as itself. In crack classification, much of the work is done with a directional filter.

$$\begin{bmatrix} 064 & 058 & 050 \\ 090 & 067 & 066 \\ 150 & 178 & 176 \end{bmatrix} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 8 & 1 \\ 1 & 1 & 1 \end{bmatrix} = \begin{bmatrix} 064 & 058 & 050 \\ 090 & 536 & 066 \\ 150 & 178 & 176 \end{bmatrix}$$

FIGURE 2 Multiplication filter.

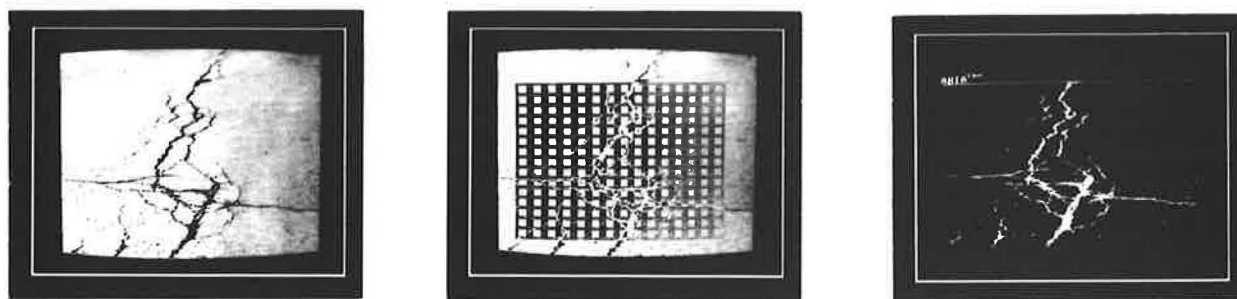


FIGURE 3 Raw image of alligator cracking on VCR playback monitor (left); picture elements of frozen image sampled for analysis as seen on image monitor (center); and image of alligator area detected and quantified by computer (right).

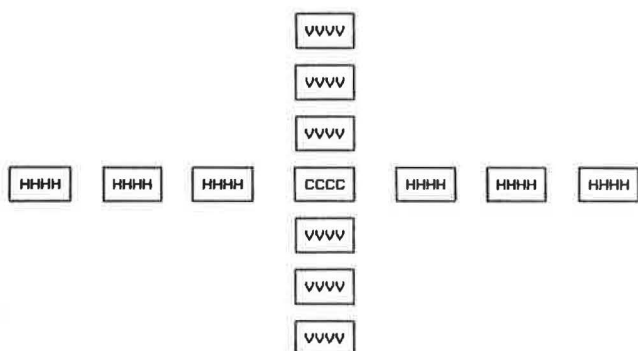


FIGURE 4 Directional filter for diagnosing cracks.

Because the directional filter splits the image into horizontal and vertical components, the vertical pixels do not get in the way of horizontal (longitudinal) crack count.

A longitudinal crack is identified from a count of the numbers of pixels in each column of the image (see the histogram shown in Figures 5–7). Pixels are counted when only a few columns have high counts and when on both sides of the high-count columns there are marked decreases in the counts. The extent (width) of cracking is determined by the abundance of high-count columns with sudden drop-offs in count. A more gradual drop-off in count describes a diagonal crack. The process for finding transverse cracks is similar to that for finding longitudinal cracks.

Type of Cracking	Number of Columns > 50% White Pixels	Number of Rows > 50% White Pixels
Longitudinal	1	0
Transverse	0	1
Large block	1–2	1–2
Block	2–3	2–3
Large alligator	4–6	4–6
Alligator	7–14	7–14
Severe alligator	>14	>14

VALIDATION TECHNIQUE

Described in the following paragraphs are the five steps used to validate the image processing measurement and quantification of a crack with actual field measurements of the same crack. A cracked concrete pavement was arbitrarily selected for this purpose. The area under consideration contained one lateral crack.

Field Measurement of Crack

In the field, the crack was measured as more than 50 in. (1.27 m) long across the pavement; however, the camera was set to capture only 50 in. (1.27 m) of the pavement. The crack was divided into 50 parts to get a measurement for each inch of the crack. Sometimes the crack width changes within the inch, so it is necessary to measure crack width two or three times within an inch. The smallest rectangular area that the crack could fit inside is 50 in. (1.27 m) laterally and 3.375 in. (8.57 mm) longitudinally (Figure 8). The measurements were taken with a measuring tape marked in 16ths of an inch.

Quantifying Density of Cracking with Field-Measured Data

Quantifying the density of the crack with field-measured data is done with the short BASIC program shown in Figure 9. The program calculates two densities. Density is defined as the area representing the crack divided by the total area under consideration or by the captured frame area as seen by the video camera and as measured in the field.

The first density is 1.4280 percent (DENSITY1) and is for the crack contained in the rectangle 50 × 22 in. (127 × 55.88 cm) denoted AREA1, the larger of the two rectangular areas selected for the image-processing program to handle. The second density is 9.3086 percent (DENSITY2) and is the same crack contained in the rectangle 50 × 3.375 in. (127 × 8.57 cm) denoted AREA2, the smaller rectangular area that the crack could fit.

The Image Processing Video Tape of the Crack

The same crack as captured on video and identified by the DMI reading 0031825 was analyzed by the image-processing algorithm. In this case, AREA1 is measured in pixels rather than in square inches. AREA1, consisting of a matrix of pixels, is 504 pixels laterally and 110 pixels longitudinally (Figure 10), and AREA2 is 504 pixels laterally and 17 pixels longitudinally (Figure 8).

Quantifying the Density of the Crack with the Image Processing Algorithm

The ARIA™ image-processing software analyzed AREA1 with 80 filter values. Filter Value 0 includes almost everything in

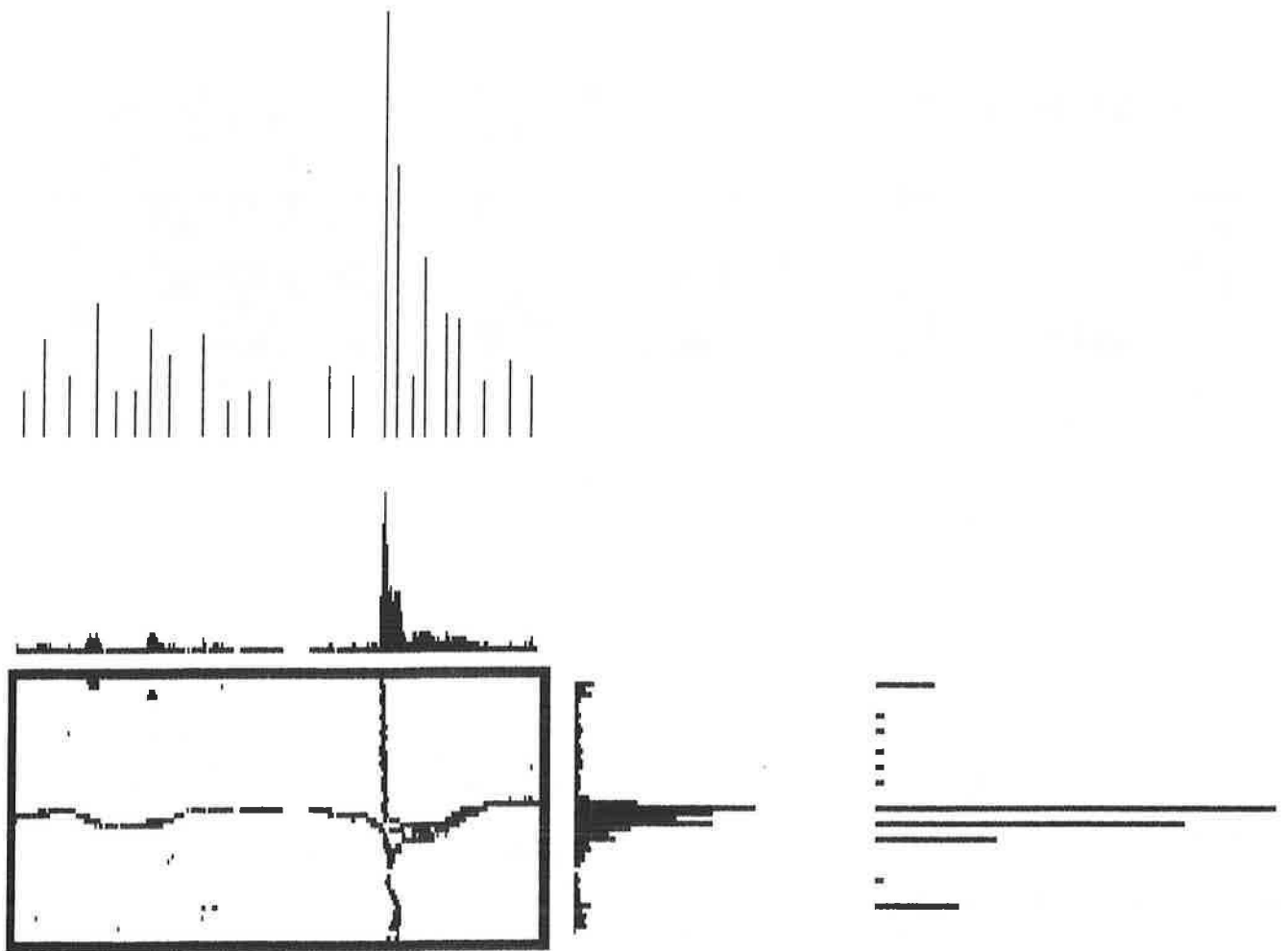


FIGURE 5 Directional histogram of lateral and longitudinal cracks.

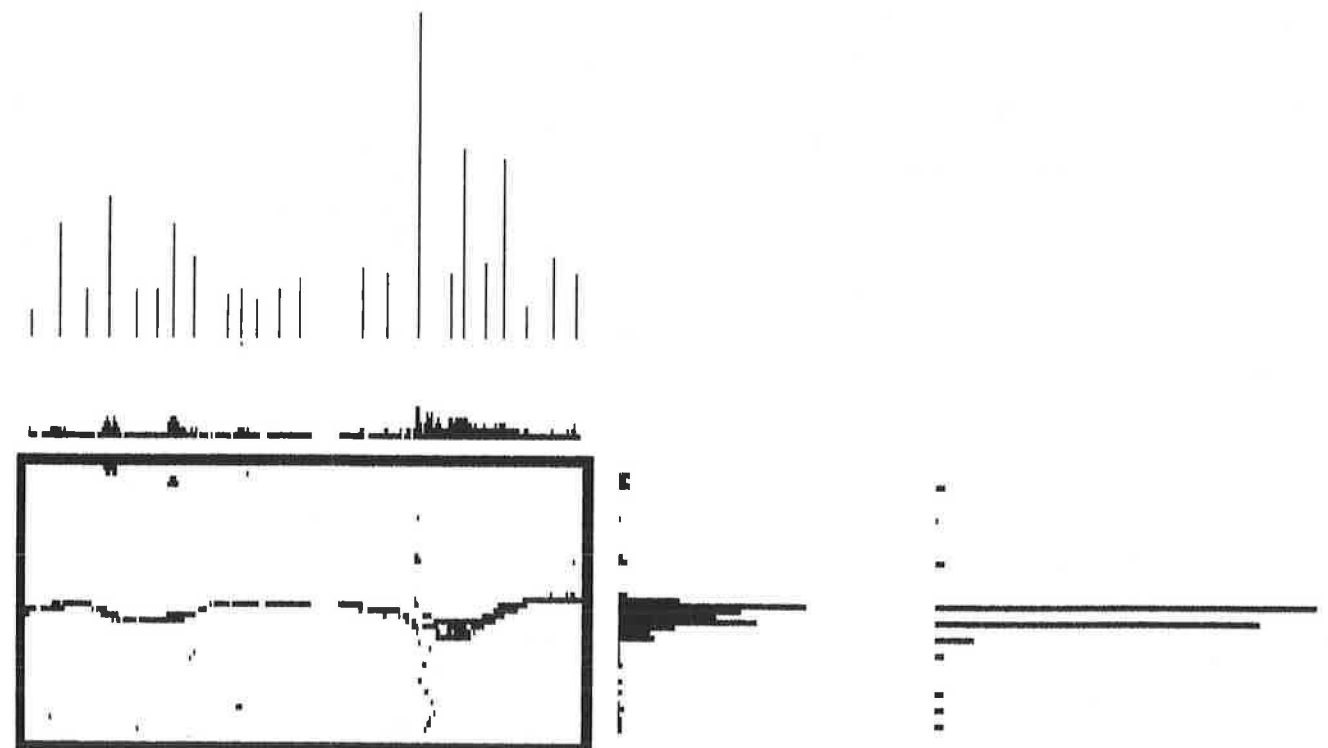


FIGURE 6 Directional histogram that identifies lateral cracks.

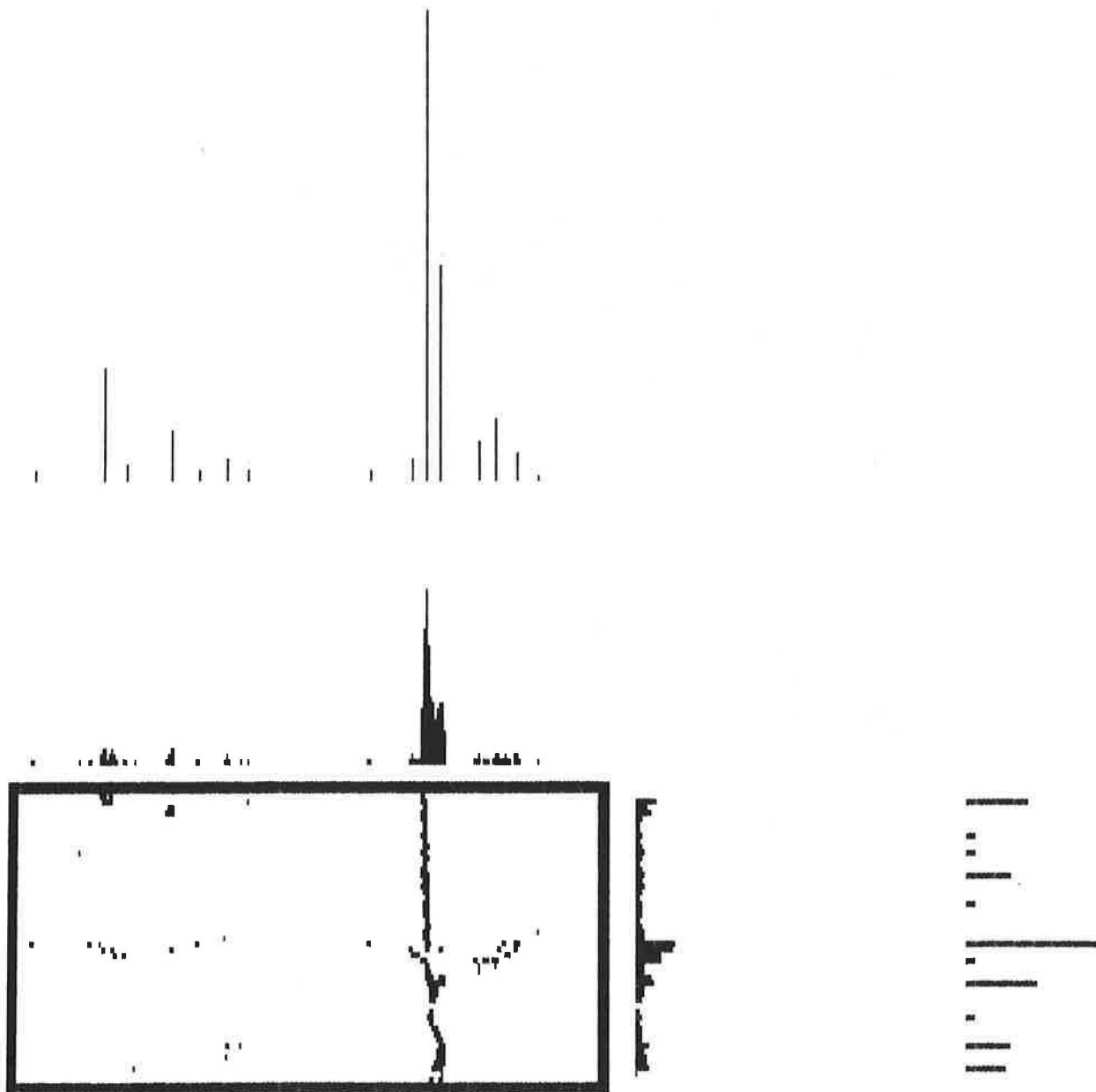


FIGURE 7 Directional histogram that identifies longitudinal cracks.

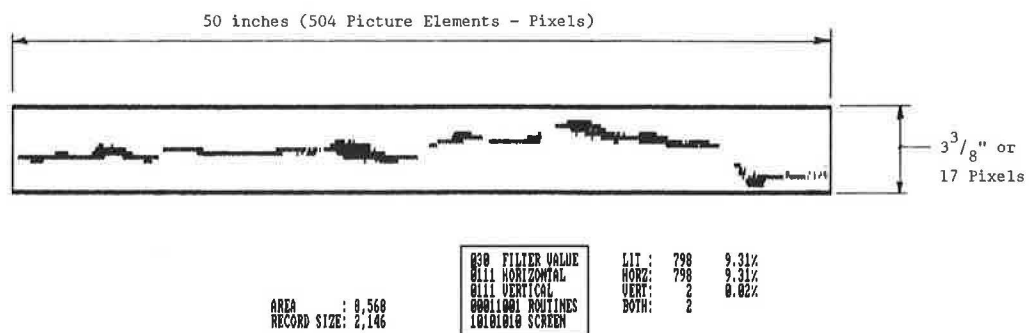


FIGURE 8 AREA2, containing 504 × 17 pixels.

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10 REM This program is written to measure the area of the crack at the
20 REM distance measuring instrument (DMI) reading of "0.031825". The program
30 REM calculates the area of the crack in lines 100 - 190. Next, the program
40 REM calculates the area of two rectangles. Then in lines 300-390 the
50 REM program calculates the percent of crack in the rectangular areas (the
60 REM density). Finally the program prints the result of the calculations.
70 REM ***** AREA OF CRACK *****
80 REM There is at least one measurement for each inch of the crack
90 REM horizontally. However, if the crack changes in width, that inch of
100 REM crack can have up to three measurements, so that each inch is divided by
110 REM parts (0 to 3) of an inch. All PARTS of each INCH are accumulated in
120 REM the variable CR (short for crack). This is an accumulation of areas.
130 REM Example: PARTS = 2 MEASUREMENTS = 0.1250 inch REM last no. on DATA line
140 REM AREA = MEASUREMENTS X (1 inch / PARTS) REM subsequent DATA
150 REM = MEASUREMENTS/PARTS
160 REM INCH=1 TO 50 REM Crack is 50 inches long
170 REM FOR PARTS REM Read measurements per inch of crack
180 REM FOR FRACTION=1 TO PARTS REM Add all meas. for this inch of crack
190 REM READ MEASUREMENTS REM Read measurement
200 REM AREA=MEASUREMENTS/PARTS REM Calculate area
210 REM CR=CR+AREA REM Accumulate areas
220 REM NEXT FRACTION REM Read next measurement
230 REM NEXT INCH REM Read next inch of crack
240 REM ***** AREA OF RECTANGLES *****
250 REM Calculation of a 50 X 22 and a 50 X 3-3/8 inch rectangle.
260 REM AREA1=50X22 REM Area 1 is 50 inches X 22 inches
270 REM AREA2=50X3.375 REM Area 2 is 50 inches X 3 3/8 inches
280 REM ***** DENSITY OF CRACKING IN AREA *****
290 REM DENS1=CR/AREA1 REM Density is the percentage of
300 REM CRACKING IN AREA 1
310 REM DENS2=CR/AREA2 REM cracking in a defined area.
320 REM ***** Print Results *****
330 REM PUS="SAMPLE AREA:## in. X ##.#### in. =####"+
340 REM "CRACK AREA:##### DENSITY:####%"
350 REM PRINT USING PUS:150,22,AREA1,CR,DENS1,100
360 REM PRINT USING PUS:150,22,AREA2,CR,DENS2,100
370 REM *****
380 REM No. of measurements per one inch (Read as "PARTS" in line 120)
390 REM #1 #2 #3 (Read as "MEASUREMENTS" in line 140)
400 REM DATA 0.2500
410 REM DATA 0.1875, 0.2500, 0.1875
420 REM DATA 0.2500, 0.1250, 0.2500
430 REM DATA 0.1250
440 REM DATA 0.2500
450 REM DATA 0.2500, 0.2500
460 REM DATA 0.2500, 0.2500
470 REM DATA 0.2500, 0.2500
480 REM DATA 0.2500, 0.2500
490 REM DATA 0.2500, 0.2500
500 REM DATA 0.2500, 0.2500
510 REM DATA 0.2500, 0.2500
520 REM DATA 0.2500, 0.2500
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690 REM DATA 0.2500, 0.2500
700 REM DATA 0.2500, 0.2500
710 REM DATA 0.2500, 0.2500
720 REM DATA 0.2500, 0.2500
730 REM DATA 0.2500, 0.2500
740 REM DATA 0.2500, 0.2500
750 REM DATA 0.2500, 0.2500
760 REM DATA 0.2500, 0.2500
770 REM DATA 0.2500, 0.2500
780 REM DATA 0.2500, 0.2500
790 REM DATA 0.2500, 0.2500
800 REM DATA 0.2500, 0.2500
810 REM DATA 0.2500, 0.2500
820 REM DATA 0.2500, 0.2500
830 REM DATA 0.2500, 0.2500
840 REM DATA 0.2500, 0.2500
850 REM DATA 0.2500, 0.2500
860 REM DATA 0.2500, 0.2500
870 REM DATA 0.2500, 0.2500
880 REM DATA 0.2500, 0.2500
890 REM DATA 0.2500, 0.2500
900 REM DATA 0.2500, 0.2500
910 REM DATA 0.2500, 0.2500
920 REM DATA 0.2500, 0.2500
930 REM DATA 0.2500, 0.2500
940 REM DATA 0.2500, 0.2500
950 REM DATA 0.2500, 0.2500
960 REM DATA 0.2500, 0.2500
970 REM DATA 0.2500, 0.2500
980 REM DATA 0.2500, 0.2500
990 REM DATA 0.2500, 0.2500
1000 REM DATA 0.2500, 0.2500
1010 REM DATA 0.2500, 0.2500
1020 REM DATA 0.2500, 0.2500
1030 REM DATA 0.2500, 0.2500
1040 REM DATA 0.2500, 0.2500
1050 REM DATA 0.2500, 0.2500
1060 REM DATA 0.2500, 0.2500
1070 REM DATA 0.2500, 0.2500
1080 REM DATA 0.2500, 0.2500
1090 REM DATA 0.2500, 0.2500
1100 REM DATA 0.2500, 0.2500

```

SAMPLE AREA:50 in. X 3.3750 in.=169 CRACK AREA: 15.7083 DENSITY: 9.3086%

FIGURE 9 BASIC program for calculating area of a crack.

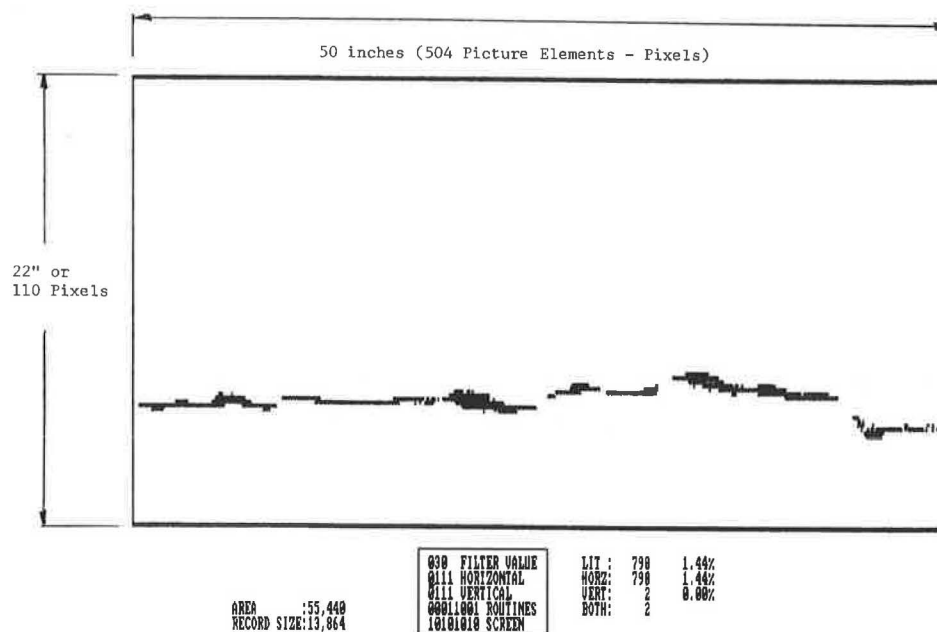


FIGURE 10 AREA1, containing 504 × 110 pixels.

the sample video frame as pavement distress. Filter Value 1 filters out some abnormalities, and Filter Value 2 filters out some more. At Filter Value 100, everything is filtered out so it appears that there is nothing wrong with the pavement. Usually, everything gets filtered out before Filter Value 80, so that is where the analysis stops. For each filter value, a certain fraction of pixels get through the filter and are included as a pavement distress. The number of pixels that are included as distress are divided by the total area under consideration. This process calculates the density of cracking in that area. These densities are graphed in Figure 11. Also graphed are the AREA2 densities for Filter Value 0 through 79.

To arrive at the filter value that describes the crack best, analysis of two areas is necessary. The relationship

$$\frac{\text{AREA1}}{\text{AREA2}} = \frac{\text{DENSITY2}}{\text{DENSITY1}}$$

is true if the crack in AREA1 is the same as the crack in AREA2. In the example at the videolog DMI reading 0031825, the 50-in. long crack (504 pixels) is present in both areas and neither area includes cracks that the other area does not have. With the field-measured data, the area of the cracks is also constant, so the following applies:

$$\frac{\text{AREA2}}{\text{AREA1}} = \frac{\text{DENSITY1}}{\text{DENSITY2}}$$

$$\frac{50 \times 3.375}{50 \times 22.000} = \frac{(\text{AREA OF CRACKS})/(50 \times 22.000)}{(\text{AREA OF CRACKS})/(50 \times 3.375)}$$

$$= 0.153409$$

The same relationship applies to image processing data.

$$\frac{\text{AREA2}}{\text{AREA1}} = \frac{\text{DENSITY1}}{\text{DENSITY2}}$$

$$\frac{504 \times 17}{504 \times 110} = \frac{[\text{AREA OF CRACK(S)}]/(504 \times 110)}{[\text{AREA OF CRACK(S)}]/(504 \times 17)}$$

$$= 0.1545454$$

The two areas are easily calculated, and they remain constant throughout all the density calculations. The densities are calculated for AREA1 and AREA2 80 times and are graphed in Figure 11. Also graphed is the resulting division of DENSITY1 by DENSITY2 multiplied by 100 for each filter value; all the calculations for that curve are presented in Table 1. The division results in Table 1 point out the correct filter value. The resulting calculation that equals AREA2 divided by AREA1 (0.1545454) occurs when the filter value is between 30 and 74. From Filter Value 0 to Filter Value 29, the processed image contains pavement texture and other abnormalities such as video noise and carries these abnormalities into the calculation of the densities. At Filter Value 30, a substantial number of pavement noise pixels have been eliminated to result in

$$\frac{\text{DENSITY1}}{\text{DENSITY2}} = 0.1545454$$

and that division result will stay at 0.1545454 up to Filter Value 74. At Filter Value 75, all the pixels have been filtered out so both densities are 0. When the filter value is 30, the pixels in AREA1 that are counted as a distress are equal to the pixels in AREA2 that are counted as a distress. They are constant from one area to the other. At Filter Value 31, the pixel count from one area will equal that of the other area,

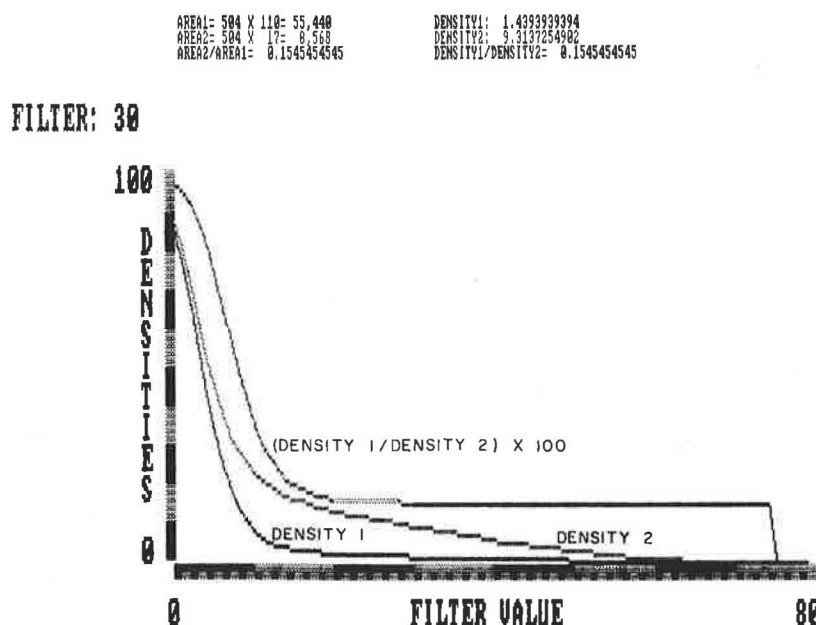


FIGURE 11 Density graphs for data in Table 1.

TABLE 1 FILTER VALUE DENSITY CALCULATIONS FOR GRAPH IN FIGURE 11

FILTER DENSITY1/DENSITY2			FILTER DENSITY1/DENSITY2		
0	86.268 /	87.873 = 0.981730	40	0.871 /	5.637 = 0.154545
1	77.273 /	80.661 = 0.957998	41	0.833 /	5.392 = 0.154545
2	66.670 /	71.977 = 0.926270	42	0.792 /	5.124 = 0.154545
3	54.717 /	62.220 = 0.879410	43	0.770 /	4.984 = 0.154545
4	43.189 /	52.451 = 0.823417	44	0.709 /	4.587 = 0.154545
5	32.989 /	44.725 = 0.737600	45	0.657 /	4.248 = 0.154545
6	24.798 /	38.049 = 0.651746	46	0.630 /	4.073 = 0.154545
7	18.699 /	32.435 = 0.576529	47	0.597 /	3.863 = 0.154545
8	14.066 /	28.595 = 0.491896	48	0.565 /	3.653 = 0.154545
9	10.696 /	25.572 = 0.418281	49	0.519 /	3.361 = 0.154545
10	8.166 /	23.156 = 0.352635	50	0.473 /	3.058 = 0.154545
11	6.389 /	21.137 = 0.302264	51	0.433 /	2.801 = 0.154545
12	5.202 /	19.549 = 0.266095	52	0.400 /	2.591 = 0.154545
13	4.311 /	18.231 = 0.236468	53	0.361 /	2.334 = 0.154545
14	3.685 /	17.204 = 0.214204	54	0.323 /	2.089 = 0.154545
15	3.231 /	16.340 = 0.197708	55	0.283 /	1.832 = 0.154545
16	2.902 /	15.651 = 0.185431	56	0.247 /	1.599 = 0.154545
17	2.675 /	14.951 = 0.178916	57	0.213 /	1.377 = 0.154545
18	2.511 /	14.496 = 0.173210	58	0.180 /	1.167 = 0.154545
19	2.363 /	14.017 = 0.168572	59	0.164 /	1.062 = 0.154545
20	2.197 /	13.364 = 0.164399	60	0.137 /	0.887 = 0.154545
21	2.089 /	12.873 = 0.162252	61	0.126 /	0.817 = 0.154545
22	1.995 /	12.442 = 0.160345	62	0.105 /	0.677 = 0.154545
23	1.899 /	11.940 = 0.159078	63	0.083 /	0.537 = 0.154545
24	1.838 /	11.660 = 0.157639	64	0.069 /	0.444 = 0.154545
25	1.762 /	11.216 = 0.157119	65	0.054 /	0.350 = 0.154545
26	1.705 /	10.901 = 0.156366	66	0.047 /	0.303 = 0.154545
27	1.643 /	10.551 = 0.155742	67	0.031 /	0.198 = 0.154545
28	1.571 /	10.119 = 0.155258	68	0.018 /	0.117 = 0.154545
29	1.508 /	9.734 = 0.154916	69	0.009 /	0.058 = 0.154545
30	1.439 /	9.314 = 0.154545	70	0.007 /	0.047 = 0.154545
31	1.387 /	8.975 = 0.154545	71	0.005 /	0.035 = 0.154545
32	1.328 /	8.590 = 0.154545	72	0.004 /	0.023 = 0.154545
33	1.282 /	8.298 = 0.154545	73	0.004 /	0.023 = 0.154545
34	1.228 /	7.948 = 0.154545	74	0.004 /	0.023 = 0.154545
35	1.171 /	7.575 = 0.154545	75	0.000 /	0.000 = 0.000000
36	1.126 /	7.283 = 0.154545	76	0.000 /	0.000 = 0.000000
37	1.066 /	6.898 = 0.154545	77	0.000 /	0.000 = 0.000000
38	1.008 /	6.524 = 0.154545	78	0.000 /	0.000 = 0.000000
39	0.945 /	6.116 = 0.154545	79	0.000 /	0.000 = 0.000000

but the count will be less than the pixel count at Filter Value 30. The pixel count will continue to fall off until Filter Value 75, when there are no pixels left.

Comparing Densities of the Same Crack Using Different Methods

At Filter Value 30, the areas AREA1 and AREA2 have the most cracking information and the least noise information. It is preferable to have those characteristics in the filter value chosen to work with. The image processing DENSITY1 (for AREA1) at Filter Value 30 is 1.439, and the field-measured DENSITY1 (for AREA1) is 1.428. If these densities are divided,

$$\frac{1.428}{1.439} = 0.99236$$

the resulting division proves to be near 1. The image processing DENSITY2 at Filter Value 30 is 9.314, and the field

measured DENSITY2 is 9.3086. If these densities are divided,

$$\frac{9.3086}{9.314} = 0.99942$$

the resulting division again proves to be near 1.

CONCLUSION

Field-measured data collection and ARIA™ image-processed data collection are two methods of data collection that yield identical results. Once the filter value has been determined for a given type of pavement, the ARIA™ image processing technology can process video images frame by frame for crack detection, diagnosis, and quantification.

The ARIA™ system is suitable for use on any type of concrete or asphalt pavement. The operator has at his disposal many filter values to adjust the fineness of his analysis. All results of analysis are stored in a data base automatically as the image processing is in progress. Graphs are also generated automatically (Figures 12 and 13). It takes approximately 0.6

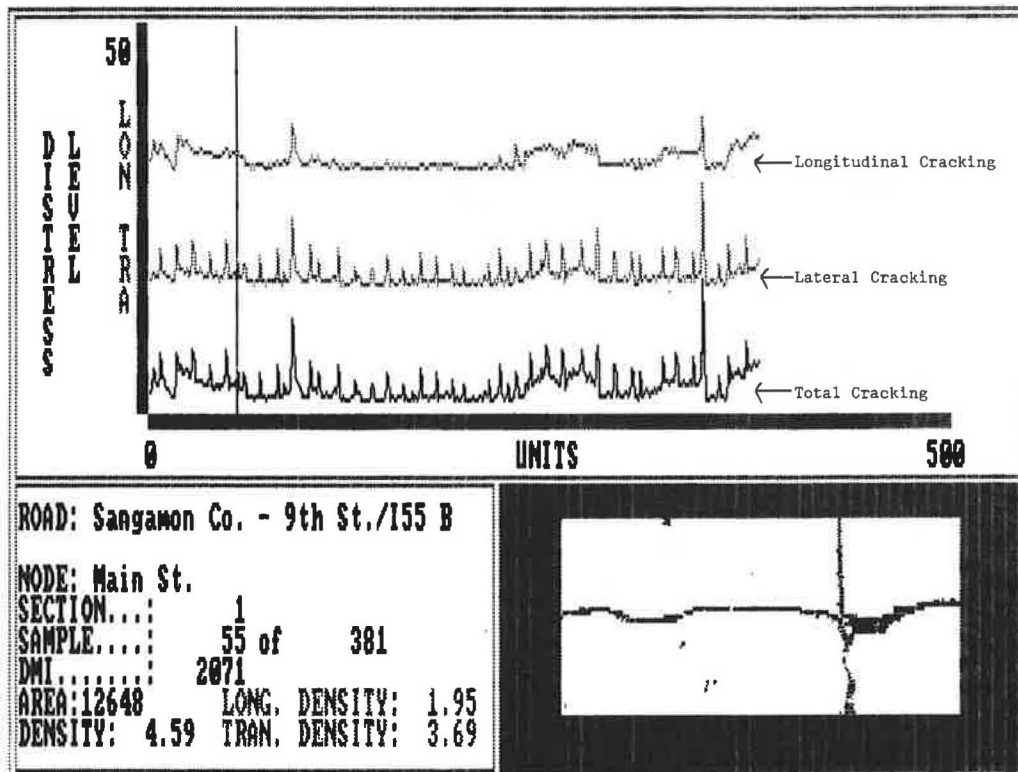


FIGURE 12 Distress levels on 9th Street/I-55B, Sangamon County.

Intersection: Main St.

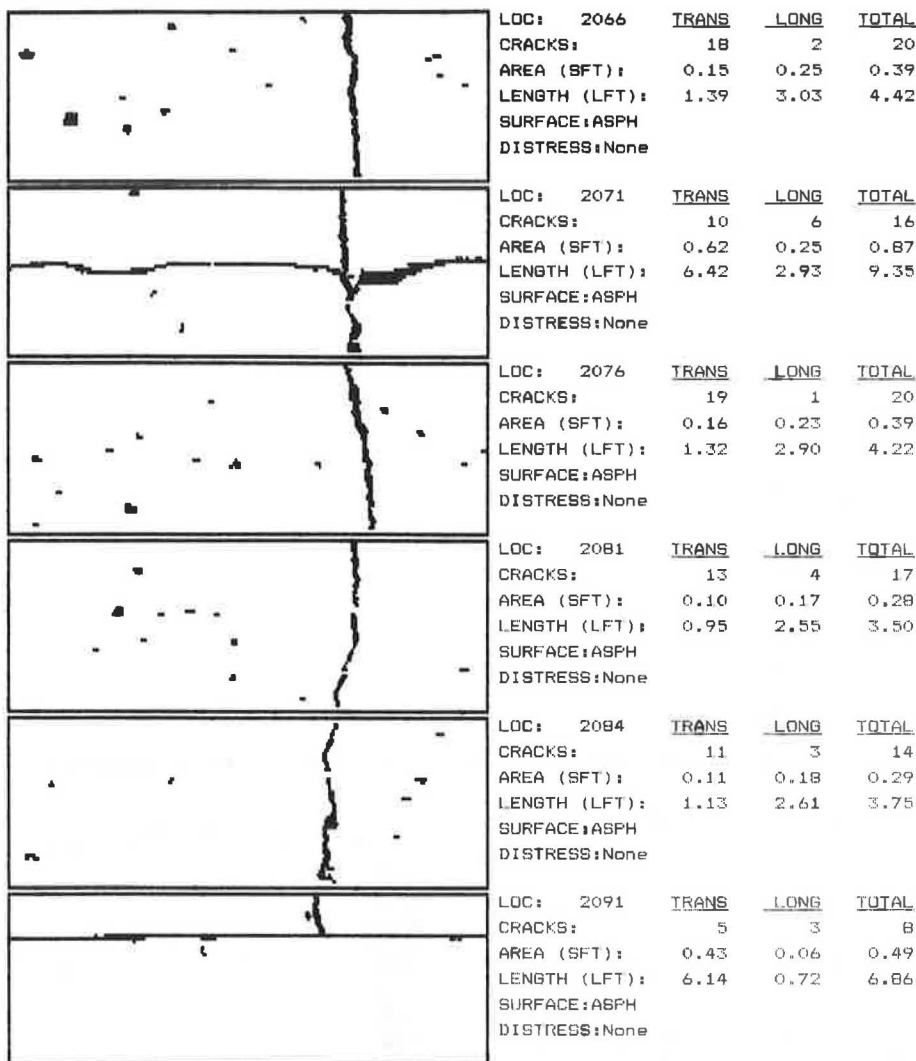


FIGURE 13 Crack identification on 9th Street/I-55B, Sangamon County.

sec to process a sample of pavement videolog (one captured frame) as compared with 1 hr or more for the same sample if it were to be physically measured in the field.

The ARIA™ system is beyond the experimental stage. The finest visible deterioration detected by the system with correct analysis in 95 percent of all cases is limited to crack width $\frac{1}{8}$ in. (3.175 mm) \pm $\frac{1}{16}$ in. (1.587 mm) at a video survey speed of 55 mph (88 km/hr). The system requires only 15 min to analyze 1 lane-mi (1.6 lane-km) of road if every foot of the pavement is captured and analyzed for cracking. Of course, this time is reduced substantially if analysis is based on the appropriate number of samples as determined by the user.

The consistency, accuracy, speed, and objectivity of the ARIA™ system of pavement distress diagnosis merit great attention from agencies that are looking for a high-quality, automated surface data collection system.

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