Noncontact Pavement Crack Detection System

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A system has been developed for the Texas State Department of Highways and Public Transportation for automated crack identification with lasers as the primary sensors. The system quickly and easily provides summary information of network pavement cracking for pavement evaluation. The development effort involved three stages. The first two stages determined the crack detection capabilities of the laser probes on the department's surface dynamics profilometer. The hardware obtained and software developed for implementing the real time crack identification and reporting system are described. The hardware includes the Selcom laser probes, the Motorola open-ended VME architecture, and a Compaq portable personal computer. The software implements two crack detection algorithms and crack reporting procedures. The system can provide real time measurements and reporting at normal highway driving speeds.

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The development effort involved three stages. The first two stages determined the crack detection capabilities of the laser probes on the surface dynamics profilometer (SDP). After experiments indicated that these capabilities were sufficient, system development proceeded.

The hardware obtained and software developed for implementing the real time crack identification and reporting system are described. The hardware includes the Selcom laser probes, the Motorola open-ended VME architecture, and a Compaq portable personal computer (PC). The software implements two crack detection algorithms and crack reporting procedures. The system can provide real time measurements and reporting at normal highway driving speeds.

A feasibility study using the SDP laser probes for crack detection and identification was conducted by Payne and Walker (*1*). For the initial studies, two lasers, one in each wheel path, acquired crack data processed on a Motorola 68000–based data acquisition board and on the Compaq portable PC. The data were sampled 16 times per inch and analyzed using several different statistical techniques. Two analysis techniques provided good results. However, these algorithms could not provide crack detection in real time with the hardware developed in this study.

Improvements have been made in the crack detection and reporting algorithms and the hardware. They afford real time processing at speeds up to 60 mph. The Motorola open-architecture VME system permits use of off-the-shelf hardware modules that are easily obtained.

CRACK DETECTION PROCEDURES

Various methods have been investigated to identify pavement cracking. However, most methods either did not provide adequate identification or did not perform in real time. Payne and Walker (*1*) describe these methods. Two methods that consistently have given better results will be discussed (*2*). Both can be run in real time although the running-mean downup method is much better than the autocorrelation difference method.

Autocorrelation Difference (Codiff) Method

Autocorrelation is a statistic that measures the correlation of data at different fixed time increments. Assuming ergodicity, the autocorrelation for lag m, denoted $r(m)$, tells if data points m time increments apart over a length of data are correlated. The autocorrelation value will be approximately zero for uncorrelated data. Data with sharp cracks will exhibit large correlation for a lag or two but the autocorrelation value decreases rapidly as the number of lags increases. Data with longer wavelength components, such as bumps, exhibit high autocorrelation values for longer lag times.

The autocorrelation difference method involves determining the spread between $r(0)$ and $r(m)$ calculated for each 1-in. (16-point) block of data. This difference is then compared with a threshold value. An estimate of the variance for zero mean data, $r(0)$, is large for data with cracking. The autocorrelations $r(m)$ for data points in the 16-point block are m time lags apart. The autocorrelation $r(m)$ (m is typically 4) decreases more rapidly if variance in the data is at a higher frequency, that is, for sharp cracks.

There are at least three shortcomings of the codiff algorithm. Because it is the relative difference between two lag values that indicates cracking, the method is unable to estimate crack width or depth. A third disadvantage of this method is that the algorithm may fail to detect a crack when one 16-point block ends and another begins in the middle of the crack.

Running-Mean Downup Method (Downup)

The downup method provides an improvement to the codiff method. The downup method can estimate both crack width

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and depth and can be executed sufficiently faster to be suited to real time applications.

The basic idea behind the downup method is that a crack can usually be identified by a sharp negative (down) slope followed by a positive (up) slope. A running mean filters the noise of the laser data and helps establish a reference plane. Figures 1 and 2 show this method on sample laser data. Figure 1 shows the sample data, the running mean of the data, and the slope of the running mean. To date, the system has used a four-point running average. (The parameter "mbar" denotes the number of points used for the running average.)

The algorithm computes the slope of the data by taking the difference between each averaged point for a base length "sbar," or for this case, seven. The third line of Figure 1 illustrates this slope or difference. The variable "diff" denotes this difference. Note that "diff" indicates a vertical depth. Because the spacings between adjacent points are equal, a division operation is not performed in computing the slope. Removing the division operation saves processing time.

The slope of the crack may consist of several points. Because the pavement surface might be changing because of an elevation change (at a sharp drop, pot hole, etc.), there needs to be a maximum value used to determine the cause of slope change. The parameter "slope" determines this. The algorithm uses this parameter when examining two elevation changes in the same direction. If both are greater than slope, the algorithm assumes an elevation change, not a crack. If a change is less than the parameter slope, or the first change is greater

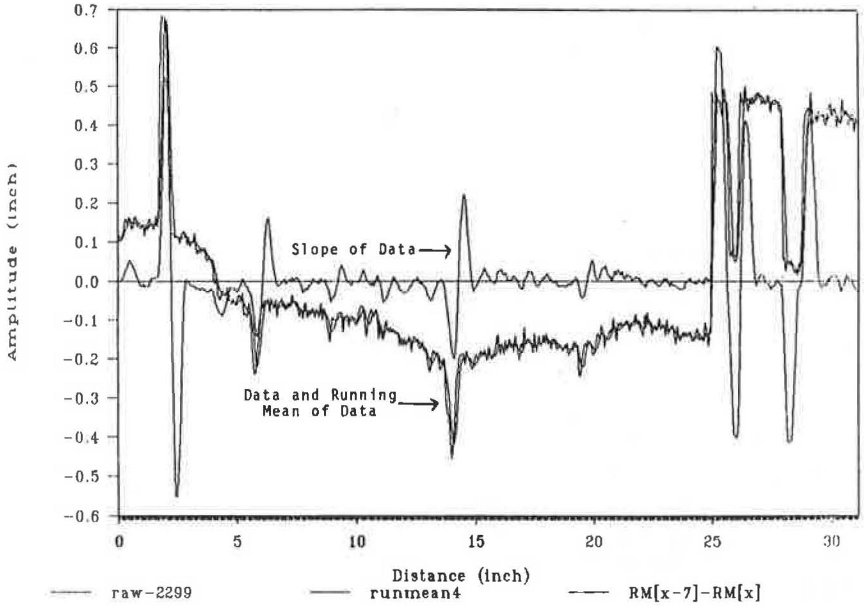


FIGURE 1 Running mean and slope test data.

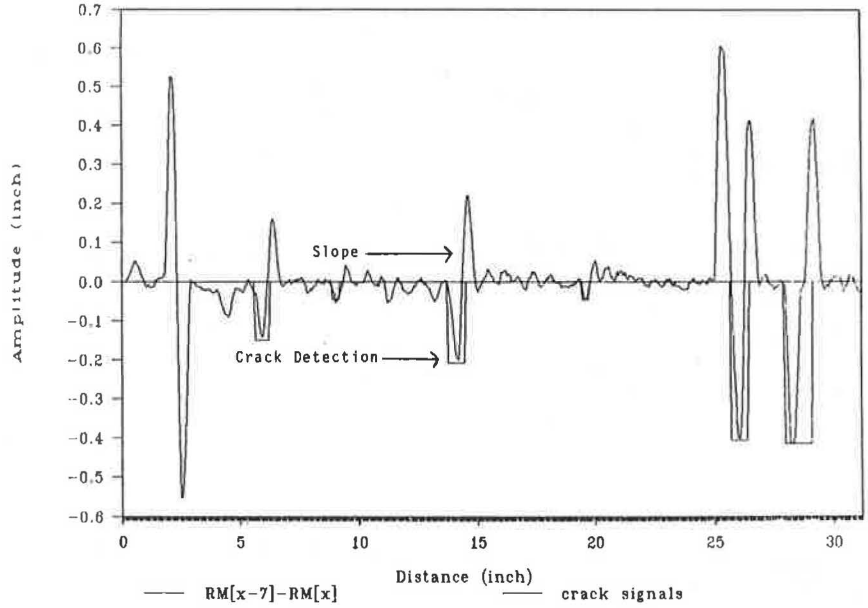


FIGURE 2 Downup crack detection test data.

but the second is not, a crack beginning is assumed. This procedure allows the detection of the crack about a reference surface.

A typical crack requires both a downward slope followed by an upward slope. Thus, the algorithm searches for an acceptable downward slope followed by an upward slope. If a second downward slope occurs, then the search restarts. Otherwise, the crack depth continues. This rule allows for slight variations in the crack characteristics. Two other parameters are used. The parameter "width" provides a maximum acceptable crack width, and "tc" for the maximum acceptable crack depth. The downup algorithm, of course, can't detect all crack characteristics, but has performed well on the pavements sampled. The best-suited set of algorithm parameters may be changed by an operator experienced in the use of the method during various field measurements.

The C code illustrates the algorithm (Figure 3).

Then, the crack may be accepted or rejected by the following statement:

```
{
if (width < max && depth >= tc)
{
```

Figure 2 shows a plot of the computed slope or vertical difference between successive points and the results of the downup algorithm of the data are shown in Figure 1. This algorithm provides estimates of both the crack width and depth. The algorithm does not interpret upward changes in the pavement characteristics as cracks. An elevation change is shown at about 25 in. with the corresponding cracks detected. The codiff method has problems with this test case. The codiff method would record each positive and negative change as a crack.

```
{       mi=0;
        si = 0;
        diff = 0;
        depth =0;          }
/*     Compute the running mean and slope */ {
        value[(mi+mbar)]=data;
        rtotal = rtotal+data-value[mi];
        rmean = rtotal/mbar;
        mean[(si+sbar)] = rmean;
        diff = rmean-mean[si];
        mi++;              }
/* Find a possible crack  */
{
      if (depth == 0)
       if (diff > slope || diff < -slope)
           {
           depth = diff;
           start = pos-1;
           }
       else;  /* normal profile frequency value, ignored*/
      else
      if (depth > 0)
        if (diff < slope)
            {
            end = pos-sbar;
            if (negative[1] !=0)
                 {
       /*           if (negative[1]< -depth)
                       depth = negative[1];
                    else
                           depth = -depth;
       */           /* write start,(depth),end */
                    depth = (-negative[1] + depth )/2;
                    fprintf(repfile, "%ld %ld %ld\n ",
                      negative[0], depth , end-negative[0]);
                 }
               else;    /* unmatched positive ignore*/
            negative[1] = 0; /* delete negative record */

            depth = 0;
           }
        else  /* diff still > slope */
           if (depth < diff)
            depth = diff;
           else ;  /* depth not increased */

      else   /* depth < 0 */
       if (diff > -slope)
           {
             negative[0]= start;
             negative[1] = depth;
             depth = 0;
           }
        else  /* diff still < -slope */
           if (depth > diff)
            depth = diff;
           else ;  /* depth not decreased */
}
```

FIGURE 3 Crack-detection algorithm as written in C code.

The parameters defined earlier adjust the detection method for the various pavement types. The values used in Figures 1 and 2 are tc = 15, slope = 11, mbar = 4, sbar = 7, and width = 32.

These numbers represent consecutive points in the vertical direction (10.8/4,096 or 0.002634 in.) for the first two parameters, and in the horizontal direction ($\frac{1}{16}$ or 0.0625 in.) for the other three parameters. This particular set of values has performed well for the pavement samples considered.

Figures 4 to 9 provide example results for asphalt pavements with severe, moderate, and slight cracking. These sections were selected during the first phase of the project (*1*) for determining the capability of the laser for detecting or recording the crack. Each section was marked and on several photographs was used for comparing each crack and its corresponding size with the laser trace. The even-numbered figures (4, 6, 8) show the results of the codiff method, whereas the odd-numbered figures (5, 7, 9) show those of the downup method. These plots indicate that both algorithms detect cracks. The codiff method does so by the greater lag difference values, discussed earlier. The downup method detects cracks by the width and depth associated with each crack, assuming it is within the specified intervals.

All figures indicate the relative displacements of the pavement surface profile. This feature allows the results of the two algorithms to be included on the same plots. That is, a constant magnitude was subtracted from the pavement surface magnitudes. The magnitudes were then scaled to inches by multiplying each value by the ratio of the laser measurement range to the full scale resolution, or 10.8 in. divided by 4,096. The magnitudes of the difference in lag values for the codiff method were not subtracted by any scale factor. In order to convert them back to their unscaled value, they would need to be multiplied by the inverse of the previous relation, or 379.3. The real time measurement mode uses and displays the unscaled values. The operator uses them for selecting the appropriate threshold value. Values exceeding this threshold indicate a crack. For the downup algorithm, the detected crack widths and depths may be read directly from the plots.

The figures indicate a major advantage of the downup method over the codiff method. The threshold values needed to detect cracks for the codiff method are sensitive to the severity of cracking. That is, a threshold around $0.3 * (4{,}096/10.8)$ should be used for slight cracking (Figure 8). However, this same value used for severe cracking (Figure 4), would incorrectly indicate too many cracks. On the other hand, for the downup method, the same set of parameters provided good results for these three levels of cracking.

Figures 10 and 11 show the use of the two methods on a different pavement texture. The pavement for this case had a seal coat that was over 1 year old. Slight $\frac{1}{16}$ to $\frac{1}{8}$ in. alligator cracks had begun to reflect through the seal coat. Figure 10 shows the codiff method and Figure 11 shows the downup method. For this pavement, an appropriate threshold would be difficult to select for the codiff algorithm. However, the downup method properly estimated the correct amount of cracking as verified by visual examination.

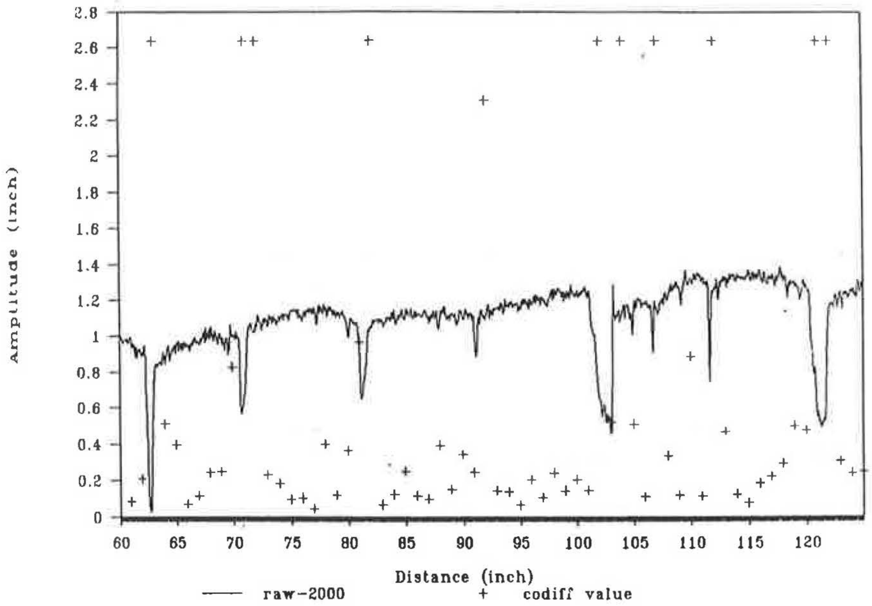


FIGURE 4 Codiff method applied to severe cracking.

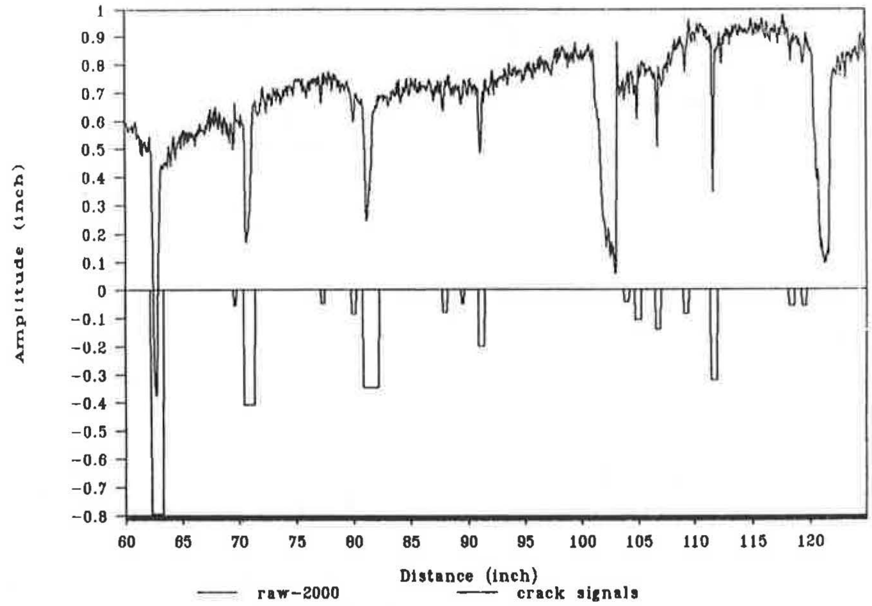


FIGURE 5 Downup method applied to severe cracking.

Of course, for some pavement surfaces it is doubtful that any algorithm would work well. For instance, a newly resurfaced pavement with a heavy seal coat can result in surface textures with the same characteristics as smooth-texture surfaces with cracks. However, such pavements wouldn't be suspected of cracking to begin with. Such a situation emphasizes the need for a trained operator in the use of the crack measurement system during the measurement process. A better determination of the performance of the algorithms on various pavement types and proper parameter selection can be determined by extensive field use.

SYSTEM ARCHITECTURE AND MEASUREMENT PROCEDURES

In this section, the parallel processing architecture and instrumentation used for real time crack detection and recording are described. This system updates the processing capability of the initial data acquisition system for real time crack measurements by replacing the 68000 PC–based data acquisition board with the Motorola open-architecture VME system. The VME system, with its various processing and I/O modules configured for this crack measurement application, will be

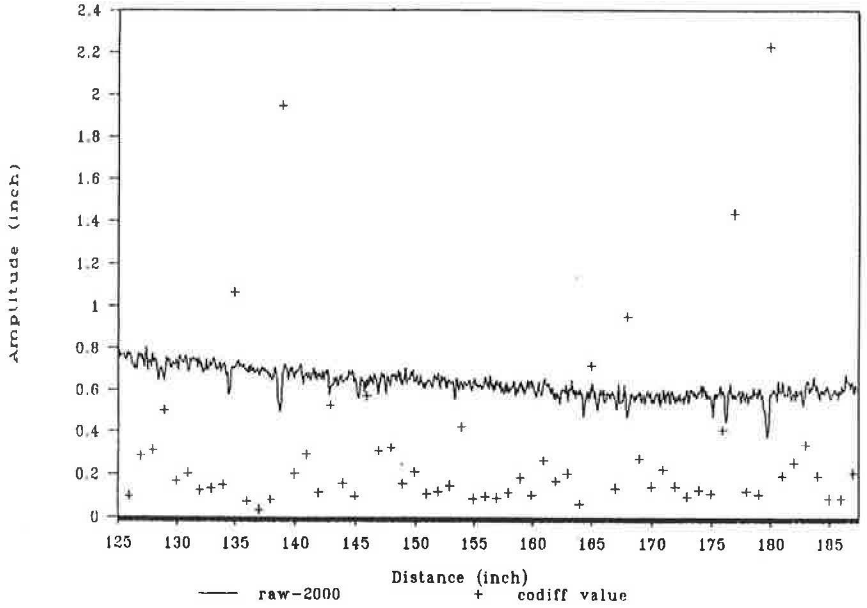


FIGURE 6 Codiff method applied to mild cracking.

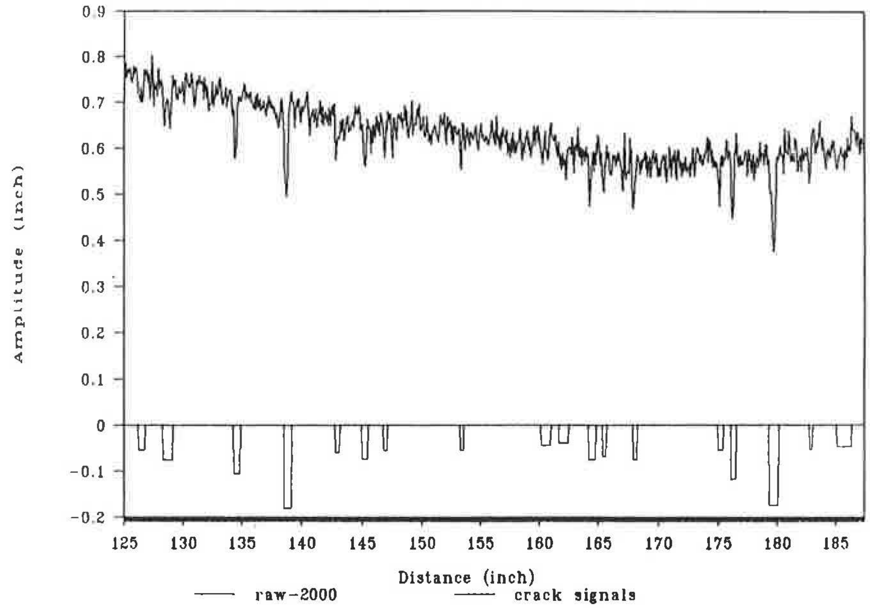


FIGURE 7 Downup method applied to mild cracking.

referred to as the real time crack processing unit (RTCPU). The RTCPU interfaces with the other system components, the Compaq computer, and Selcom lasers. The RTCPU structure supports multiple lasers. Payne and Walker (*1*) discuss details of the laser and Compaq system components. Next is a brief description of these subsystem components, followed by a description of the overall parallel processing system architecture of the RTCPU. Figure 12 shows the crack measurement system components.

The Selcom Optocator

The Selcom Optocator is an optoelectronic measurement system that measures the distance to an object. The basic components of the optocator are the noncontact laser probes, the probe processing units (PPUs), and the CPU subrack containing the power supply and receiver-averaging boards. The receiver-averaging boards receive and process data from the laser probes. An optocator interface module that

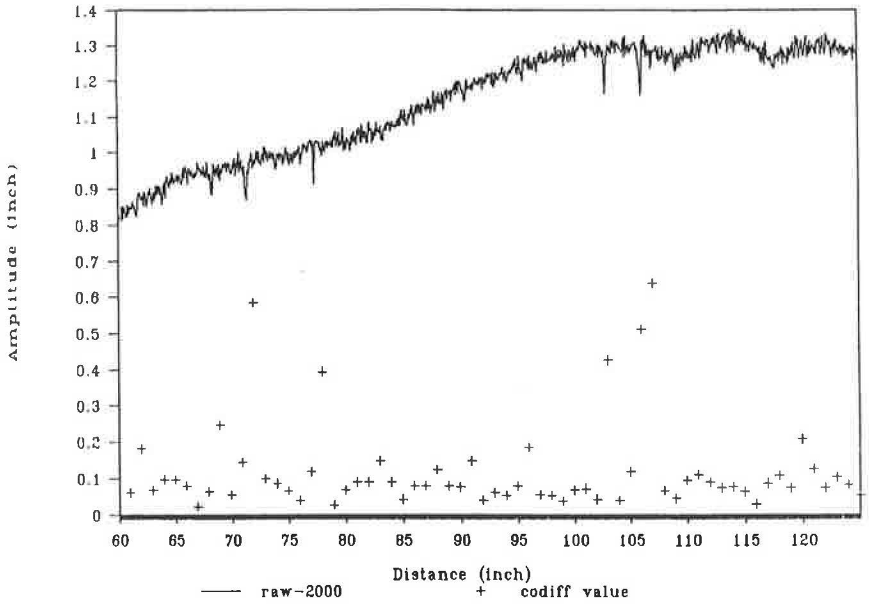


FIGURE 8 Codiff method applied to slight cracking.

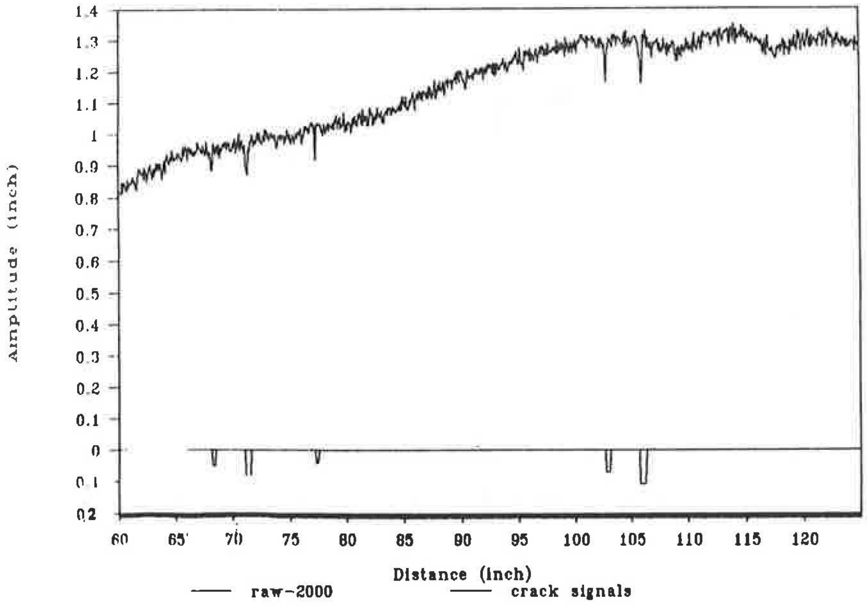


FIGURE 9 Downup method applied to slight cracking.

plugs directly into the VME bus can replace this last component.

The laser probe contains a pulsed, modulated (32-kHz), and intensity-controlled gallium arsenide (GaAs) laser diode; a position-sensitive photodetector; and an appropriate lens system. The GaAs laser probe emits pulsed, modulated invisible infrared light. These pulses occur at a frequency of 32 kHz. This frequency accounts for the 32-kHz data rate of the serial data passed to the receiver-averaging boards. The light from the laser beam passes through a lens that focuses the light in the center of the measurement range. The spot size striking the pavement surface is approximately ¼ by ¹⁄₁₆ inch. The PPU processes the analog signal from the laser probe and sends the signal in digital form to the RTCPU.

RTCPU Functions

The RTCPU receives the laser data from the optocator and performs the crack detection function by the real time pro-

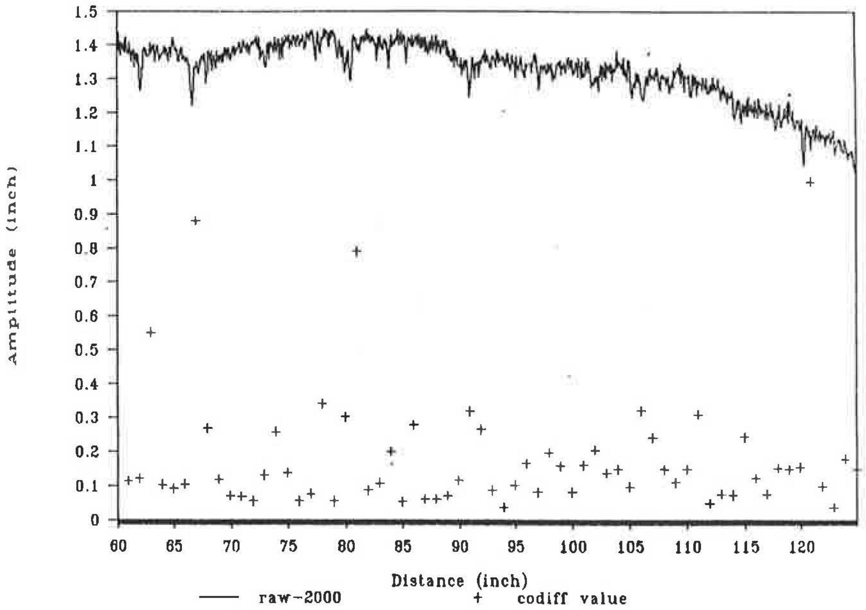


FIGURE 10 Codiff method applied to seal coat with alligator cracking.

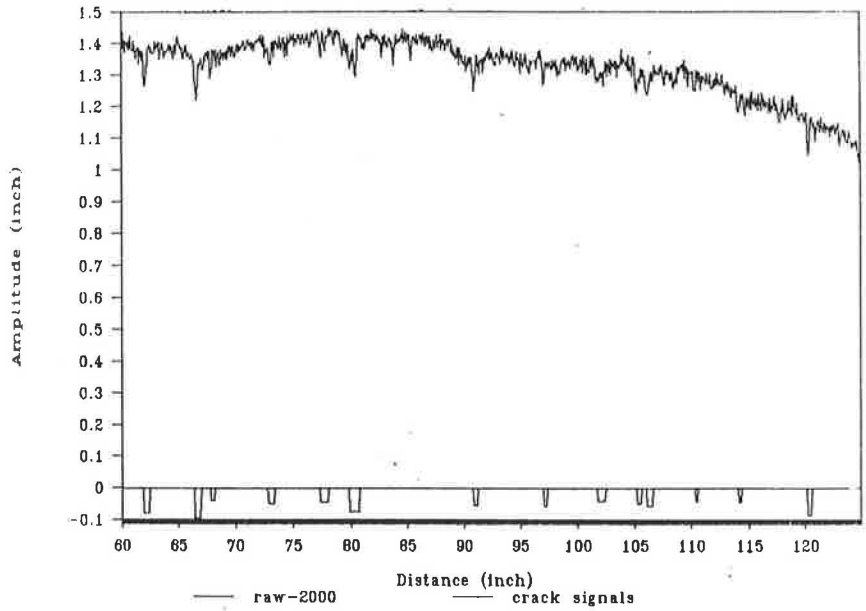


FIGURE 11 Downup method applied to seal coat with alligator cracking.

cessing of the crack detection algorithm. The VME system architecture of the RTCPU allows the designing of various general-purpose computing systems by purchasing a basic cardcage with the VME bus interconnect standard.

The Compaq Portable PC Subsystem

The Compaq portable PC is the user's interface to the entire system. From the keyboard, the user can run the real time crack detection and recording activities, perform various system diagnostics, or collect raw laser data. The programs that provide crack reporting and recording run on the Compaq. The real time crack count provided by the RTCPU provides a rough estimate of the number of cracks seen as the vehicle moves at highway speeds. Software in the Compaq summarizes, displays, and records this information in the form of frequency counts for specified pavement intervals.

Crack Measurements and Recording

The laser crack measurement system is currently configured to implement both the codiff and downup algorithms. These

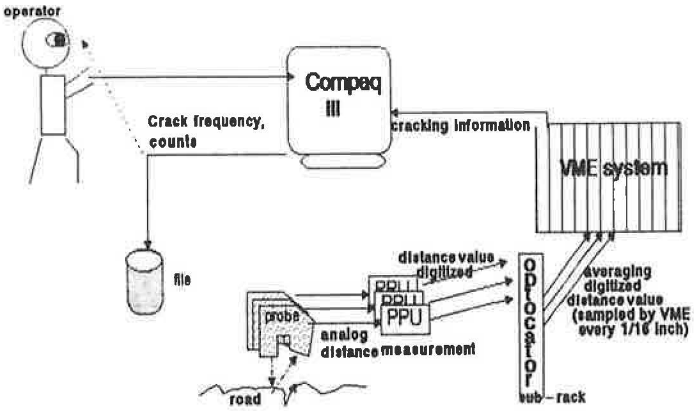


FIGURE 12 Crack measurement system.

algorithms initially indicate crack detection and its magnitude. The codiff method specifies only the lag differences between autocovariance values indicating possible cracks, whereas the downup method can provide an estimate of both the crack depth and width. Both methods provide cracking information for each inch sampled in the distribution mode. When in the magnitude frequency count mode, the codiff method still provides the lag difference magnitudes for any crack for a 1-in. resolution, whereas the downup method provides a summary of the crack depth. Although crack width is also measurable using the downup method, the two modes currently implemented do not provide it.

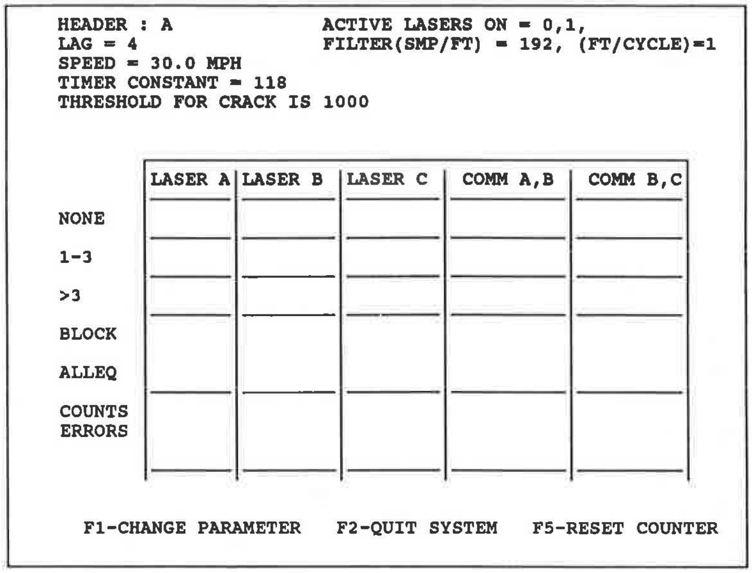
During the distribution mode, the PC keeps track of the individual and common laser crack counts as reported from the master. The system displays the information on the CRT and records it to disk. Figure 13 shows the screen used for displaying this information and the system parameter information. The PC tracks, displays, and records data for the operator, i.e., the number of detected cracks found within each of the three count intervals for each foot for a specified distance interval. Thus, for a distance indicated by a distance reporting signal (which can be manually selected) the three intervals selected provide the number of times that

- There were no cracks detected in a foot,
- One to three cracks were detected in a foot, and
- Greater than three cracks were detected in a foot.

This information is displayed for each laser (up to three) and for the two adjacent lasers (Lasers 1 and 2, and 2 and 3).

These statistics were selected to help estimate alligator and block cracking in the measurement interval. Room is available on the screen to indicate the amount of alligator and block cracking, although it is not currently implemented.

The screen for the crack count mode is shown in Figure 14. This mode allows the user to determine what the various crack detection thresholds or depths should be for a given pavement type. The PC accumulates the number of times the cracking magnitudes fall within 12 different user-selected intervals. The system records both the distribution and the count information on disk for later off-line evaluation. The system creates a similar file for the normal crack measurement and recording modes.

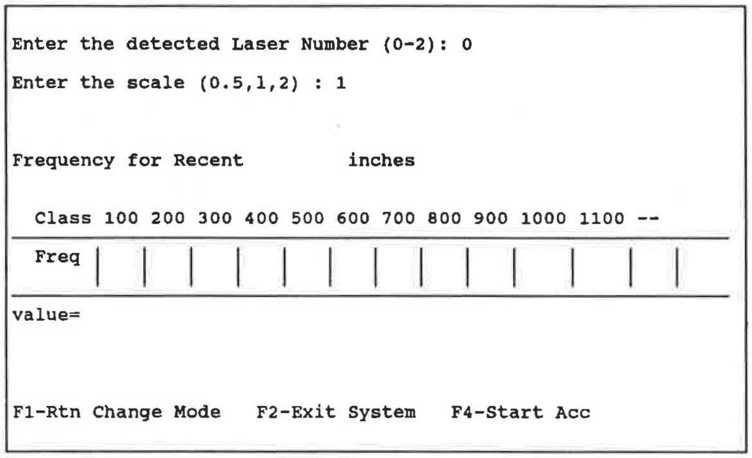


```
HEADER : A                  ACTIVE LASERS ON = 0,1,
LAG = 4                     FILTER(SMP/FT) = 192, (FT/CYCLE)=1
SPEED = 30.0 MPH
TIMER CONSTANT = 118
THRESHOLD FOR CRACK IS 1000


           | LASER A | LASER B | LASER C | COMM A,B | COMM B,C |
NONE
1-3
>3
BLOCK
ALLEQ
COUNTS
ERRORS


   F1-CHANGE PARAMETER   F2-QUIT SYSTEM   F5-RESET COUNTER
```

FIGURE 13 Crack reporting and status screen.



```
Enter the detected Laser Number (0-2): 0

Enter the scale (0.5,1,2) : 1


Frequency for Recent         inches

  Class 100 200 300 400 500 600 700 800 900 1000 1100 --
  Freq |   |   |   |   |   |   |   |   |   |    |    |    |

value=



F1-Rtn Change Mode    F2-Exit System    F4-Start Acc
```

userlag.sc3

FIGURE 14 **Crack count distribution screen.**

CONCLUSIONS

A system for implementing real time crack identification and reporting has been described. The crack measurement hardware includes the Selcom laser probes, the Motorola open-ended VME architecture, and the Compaq portable PC. The software implements two crack detection algorithms, and crack reporting procedures. The system is capable of real time measurements and reporting at highway driving speeds up to 60 mph.

Several important conclusions result from this study. First, alligator and block pavement cracking can be detected using the Selcom lasers mounted in the wheel paths. Transverse cracking is more difficult to measure. The three-laser configuration with the common cracking measurements would provide a method to detect such cracking. This configuration provides a way of measuring cracking across the lane. Multiple lasers also allow rutting to be detected.

This system is limited by trying to detect cracking using only two or three narrow beams of laser light. Obviously, massive amounts of information across the lane are not available.

The system is currently planned for more extensive field implementation. The usefulness of the system for providing crack measurements for the state's future pavement management system or the current PES can only be determined from such extensive field usage.

As a final comment on the usefulness of this system, several low-cost lasers have recently been introduced that would greatly enhance the system by providing additional traces for each wheel path. It is planned to investigate these lower-cost lasers for use in the system.

REFERENCES

1. D. Payne and R. S. Walker. *The Use of Lasers For Pavement Crack Detection.* Texas State Department of Highways and Public Transportation Research Report 1141-1. University of Texas at Arlington, Dec. 1988.
2. R. S. Walker and C. Kuo. Pavement Crack Detection with Lasers. Texas State Department of Highways and Public Transportation Research Report 1141-2F. University of Texas at Arlington, Jan. 1990.

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