DIGITAL DISTRESS SURVEY OF AIRPORT PAVEMENT SURFACE

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ABSTRACT

Accurate data collection and interpretation of pavement data is critical for the decision-making process in pavement management. Collection and analysis of pavement surface distress is still a manual process for many highway and airport agencies, even though substantial amount of resources were used in the past decades to devise automated approaches to collecting and analyzing pavement surface distress. This paper introduces a new automated system capable of collecting and analyzing pavement surface distress, primarily cracks, at real-time through the use of high resolution digital camera, efficient image processing algorithms and multi-computer, multi-CPU based parallel computing. It is shown in the paper that distress results from the automated system are consistent for multiple passes of the same pavement sections. In addition, the digital system was used to survey two runways of the Hartsfield Atlanta International Airport in late November 2001. The FAA guide for airport distress survey is used in the analysis. As the automated digital system was not designed for PCI rating, manual survey was used to collect distress information from the digital images of the two runways.

INTRODUCTION

In recent years, capability of collecting images of pavement surface was added to the data vehicle for pavement condition analysis. The integrated multi-function data collection vehicles serve the purpose of gathering varieties of data on roadway and roadside structures for highway agencies. Data of ride quality and rutting can be collected at highway speed. Up to recently, there still existed a number of limitations in the collection and analysis of another data set: pavement surface distress. This paper presents a new automated system capable of collecting and analyzing pavement cracks at real-time and with high-resolution digital images.

As a part of a larger research effort to develop a digital highway data vehicle started in the mid 1990s, the researchers at the University of Arkansas focused on the development of a high performance, automated system for distress survey. This paper discusses the principles of the algorithms for image processing to identify and classify pavement cracks and the parallel computing structure used in the processing. The result of the analysis demonstrates the advantages in consistency and speed of using the automated system for distress survey.

This paper also presents a recent data collection and analysis effort for two runways of the Hartsfield Atlanta International Airport. The analysis was conducted with the PAVER method and PCI values were calculated based on the FAA guide for pavement surface distress survey.

DESCRIPTION OF THE AUTOMATED SYSTEM FOR PAVEMENT SURFACE DISTRESS SURVEY

In recent decades, technological innovations in computer hardware and imaging recognition techniques have provided opportunities to explore new approaches to automating distress survey in a cost-effective way. Wang (2000) presents the developments in the last two decades regarding several important systems. This section describes the automated system.

Speed, Accuracy, and Crack Geometry

Real-time processing is defined as processing data at the same data throughput as the vehicle is collecting images at highway-speed normally between 80 to 100 KPH. When the in-office processing speed is equivalent to vehicles' traveling highway speed, the off-line processing can be viewed as real-time processing. However, on-line processing as the vehicle is collecting data is the ideal approach for users to obtain data quickly, which is applied in our research. When the data vehicle returns from a data collection trip, the database in the information system can be quickly downloaded into a central computer server, and pavement distress data including images and analysis results can be immediately reviewed and used by users.

Two key issues to be considered in automated survey of pavement surface distress include improving processing speed, and developing sufficiently accurate algorithms and their implementation. One important aspect of detecting distress is that highway pavement surface may contain numerous foreign objects, such as oil residue, dirt, lane markings, vehicle's tire mark, tree limbs, and other non-distress related items. It is important to develop algorithms to correctly distinguish the distresses or cracks from these non-distress items. In addition, certain images collected in the field may also possess a quality level that may not be sufficient enough, therefore resulting in additional difficulty in processing.

Furthermore, there are various methodologies for pavement distress indices. In other words, there is no standard, such as IRI for roughness, for pavement distress. For this research, the objective in the image processing for cracks then became producing geometric features of cracks. Separate algorithms are then to be applied to the geometric features of the cracks to produce respective crack indices. The technical approach of image processing was to develop statistics and geometry based image analysis techniques, and to implement the algorithms in an integrated image acquisition and processing computing system in an effort to achieve real-time processing with sufficient accuracy.

The image acquisition sub-system continuously provides the processing sub-system pavement surface images with complete coverage of the pavement surface in a roadway network. The implementation of the developed algorithms in a parallel computing environment produced a real-time system that can automatically identify and classify pavement surface cracks while high-resolution digital images are being acquired and archived into a multimedia database at highway speed. This image processing system for cracks is called distress analyzer.

The first step in the image processing process is to distinguish any cracks from other non-distress noises. The primary method in this step relies on analytical descriptions of distresses' characteristics. The second step is to connect and vectorize the detected cracks, and establish a distress database related to location, orientation, and size of each crack. Based on the geometric information obtained in the second step, cracks can be classified using any pre-defined distress categorization protocols. The result of the analysis is contained in a database regarding the location and geometry of individual cracks. Several distress categorization protocols are incorporated into the system to generate surface crack indices, including AASHTO Designation PP44-00 (AASHTO 2000), Texas distress manual (Texas Department of Transportation 1999), and Universal Cracking Indicator (CI) (Patterson 1994) from World Bank. Similar to determining IRI for roadway roughness, these indices are immediately computed and available for analysis when the vehicle completes a data collection field trip.

Figure 1 illustrates the framework of the data acquisition and processing in a parallel environment. A dual-CPU computer is used for data acquisition of GPS data, DMI data, and images from the digital camera at 12 frames per second. These data sets are moved to a multi-CPU computer at real-time for the distress analyzer. The distress analyzer has a project manager for parallel processing, which coordinates the processing of images among the *n* processors. The current implementation is using two CPUs for the distress analyzer. Figure 2 shows a screen shot of the distress analyzer working at real-time with two Pentium-III processors at 733-MHz per CPU. As can be seen from Figure 2, two analyzers were launched in parallel with combined processing speed over 40 MPH with corresponding two side-by-side processes. At the bottom of both processes are the analysis results for crack geometry and basic classification. Each process shows the original image on the left and processed binary image on the right. Each binary image shows identified cracks in bounding boxes with a unique integer number for each bounding box. A rectangular-shaped bounding box contains one crack. The right-most window illustrates the processing status of the two analyzers. With a computer containing two Pentium 4 processors at 2.0-GHz per CPU, the processing speed for the distress analyzer is well over 60 MPH on consistent basis.

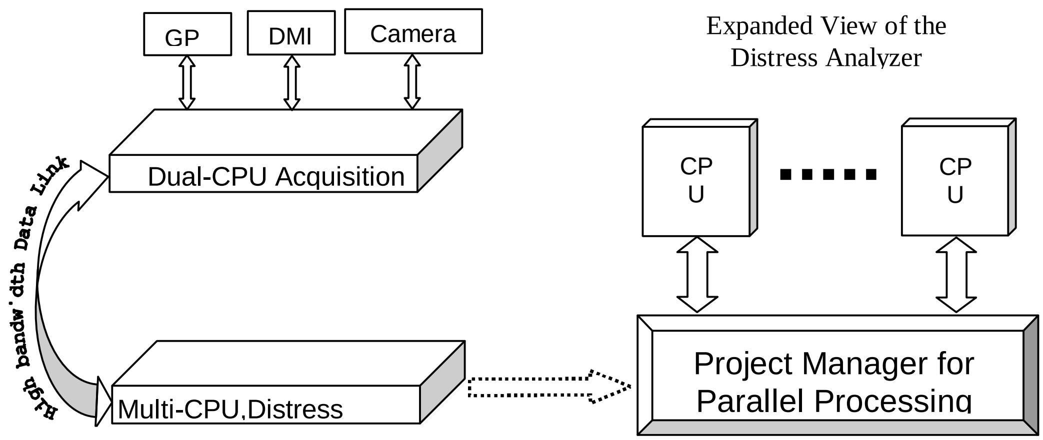

Figure 1 The Framework of the Data Acquisition and Processing

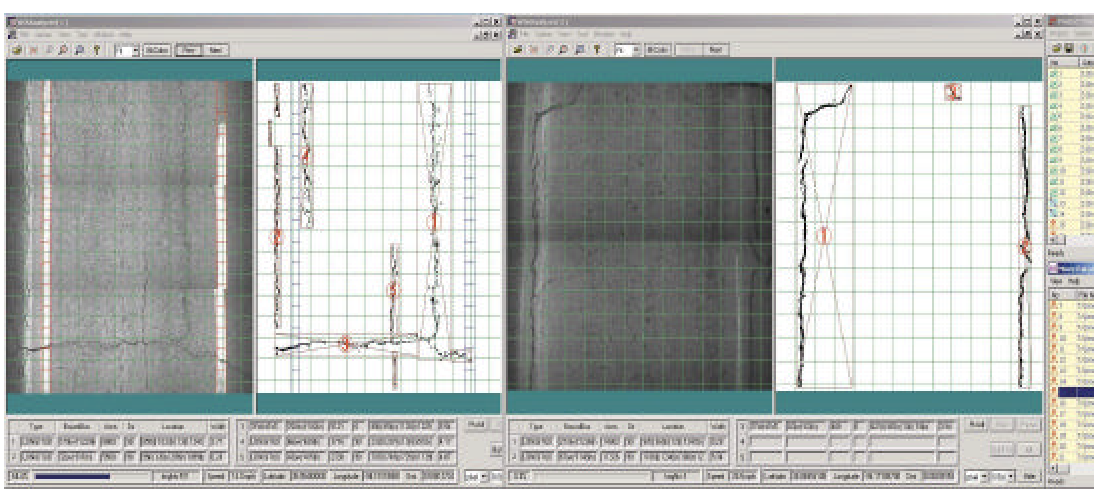

Figure 2 Dual-Processing for Cracks in a Parallel Environment with the Crack Analyzer

ANALYSIS OF MULTIPLE RUNS ON THE SAME ROAD SECTION

Test runs were conducted four times for the same 2.8-mile road section to verify the repeatability of the system. According to the analysis above, the Universal Cracking Indicator (CI) was used for the analysis. The Figure 3 shows the chart with data from the four test runs.

The pavement crack analyzer yielded very similar crack information on the same pavement section. Different test runs show the same pattern in the chart, which indicating the same trouble spots on the pavement. To quantify the repeatability of the crack recognition system, the standard deviation of the Universal Cracking Indicators (CI) for each sub-sections are calculated. The average of the standard deviation is about 15% for the average CI value for the entire 112 data points.

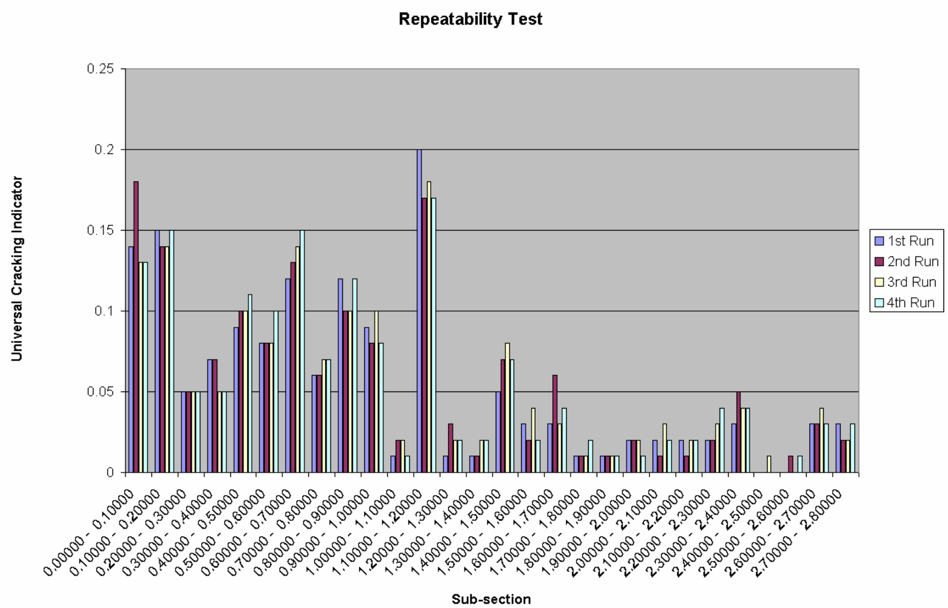

Figure 3 Four Test-Runs with Universal Crack Indicator (CI)

RUNWAY SURVEY PROJECT

The runway survey project was conducted in November 2001 with R&D Testing & Drilling, Inc and ACE-Aviation Consulting Engineers in Atlanta, Georgia. The scope of the survey includes two runways of HAIA, Runway 8R and Runway 9L, and using Pavement Condition Index (PCI) method for data analysis. Guidelines provided by FAA (Guidelines and Procedures for Maintenance of Airport Pavements) and engineering staff associated with the airport pavement management are followed in the analysis and reporting.

The runways were constructed with jointed concrete pavement. There are 6 lanes on each runway, which are identified as A, B, C, D, E, and F, starting from the North edge to the South. There are 134 slabs in each lane for Runway 8R. The typical slab dimension is 75 ft long and 25 ft wide except the second slab in sample unit 8R-16-119, 8R-36-316 and 8R-56-516. These three slabs are 25 ft long and 25 ft wide. There are 185 slabs in each lane for Runway 9L. Slabs in this runway have three different dimensions. Some slabs are 25 ft long by 25 ft wide, some are 50 ft long by 25 ft wide, and some are 75 ft long by 25 ft wide.

Figure 4 The Data Vehicle for the Runway Survey

SECTIONING OF RUNWAYS

Figure 5 on the left shows the end section of Runway 8R and Figure 6 shows detailed information on sectioning. The two left-most lanes are referred to as Left Outboard, the two inner lanes are Keel, and the two right-most lanes are Right Outboard. Sample units occupy two lanes across the entire width of either Outboards or Keel. Each sample unit of the runway pavement is given an identity in the format of Runway_Designation-Section_Number-Sample_Unit. For example, the top left sample unit in the figure is identified as 08R-21-136. It means that it is the sample unit 136 of section 21 in Runway 8R.

Within the Left Outboard, Keel and Right Outboard, the pavement is subdivided into sections, each of which includes a number of sample units. For instance, in Figure 5, the Left Outboard consists of section 18, 19, 20 and 21. Keel consists of section 38, 39, 40 and 41. The Right Outboard consists of section 58, 59, 60 and 61. Within each section, it is subdivided into sample units. For instance, section 18 of Left Outboard consists of sample unit 125, 126, 127, 128, 129, 130, 131 and 132. Section 19 of Left Outboard consists of sample unit 133. Within each sample unit, it is subdivided into several concrete slabs, many of which are 75-ft long. For instance, sample unit 125 is made up of three concrete slabs. Sample units 126 through 131 are made up of four concrete slabs. Each concrete slab is then subdivided into imaginary 25 ft fraction in the longitudinal direction as shown in Figure 6. For instance, a 75 ft concrete slab is made up of three imaginary 25 ft fraction and a 50 ft concrete slab is made up of two imaginary 25 ft fraction. The 25-ft imaginary slabs are used as the base unit for collecting distress data for PCI.

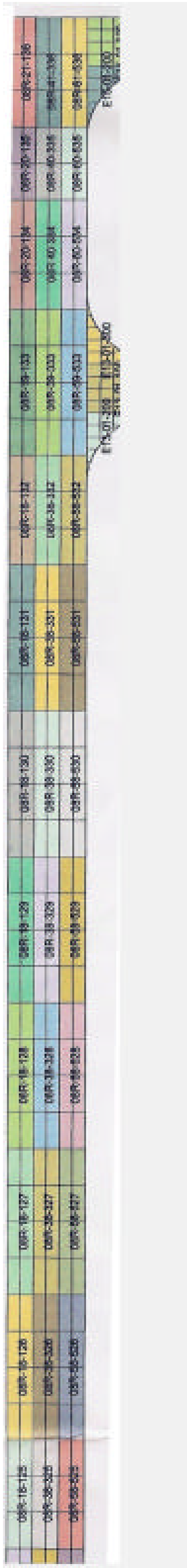

Figure 5 Sectioning of Runway of HAIA

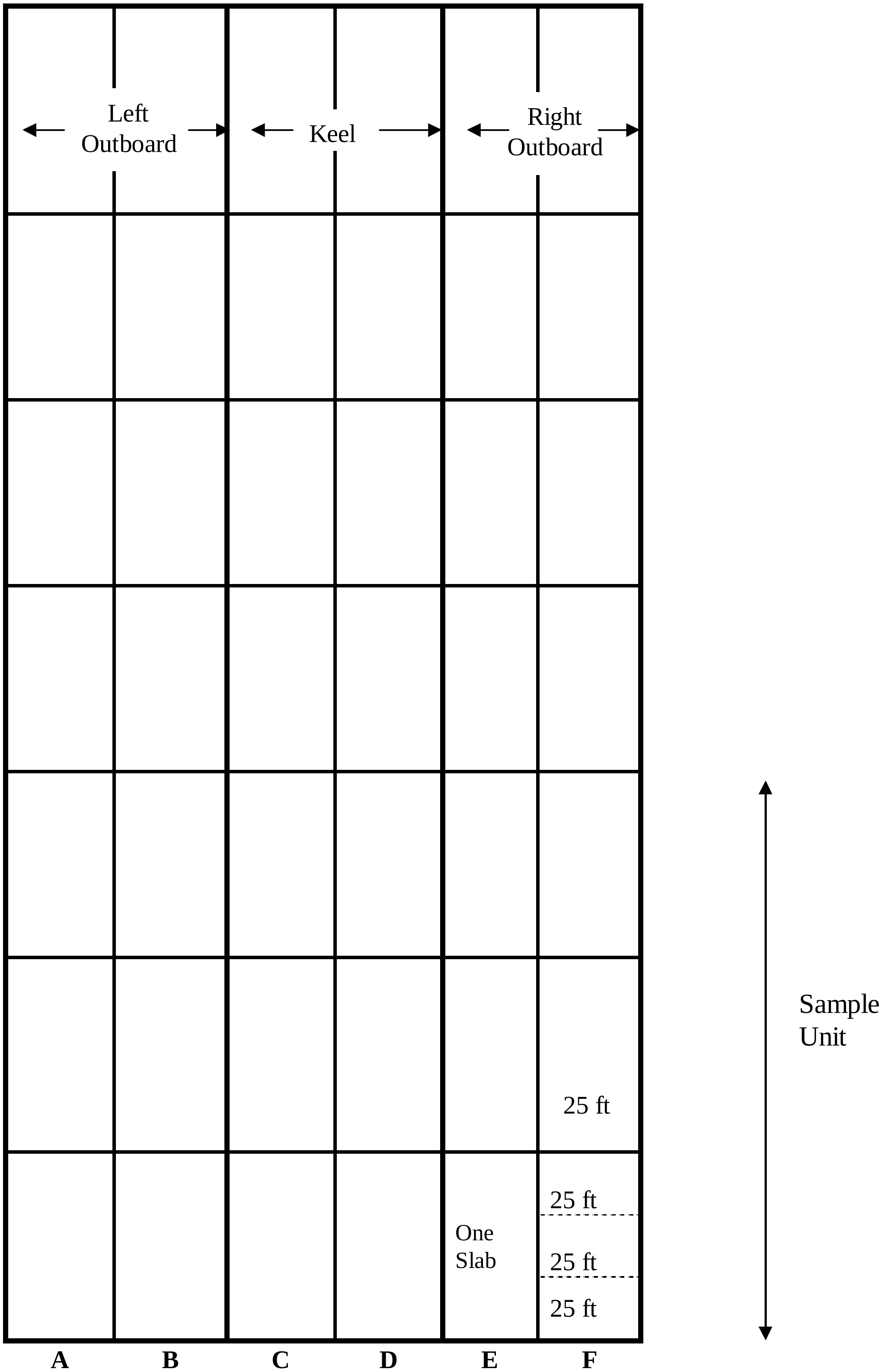

Figure 6 Section, Sample Unit, and Imaginary Slabs

USING PCI FOR CONDITION SURVEY

The Pavement Condition Index (PCI) method used in the project follows the recommendations provided by U. S. Department of Transportation in "Guidelines and Procedures for Maintenance of Airport Pavements", later referred to as the Guideline. The guideline can be downloaded from the web site http://av-info.faa.gov/dst/ACreference/150.htm.

According to the Guideline, a project is divided into sections with similar pavement design, construction history or traffic area. Each section is further divided into sample units. The Guideline recommends 20 slabs (with joint spacing not to exceed 25 feet) as a sample unit for airfield runway. However, Hartsfield Atlanta International Airport has its own method in sectioning runway pavements as discussed on previous pages. The runways have been delineated into predetermined sections and sample units for the initial implementation of microPaver. Each sample unit is inspected for distress type and its severity, and documented for every concrete slab (or 25 ft fraction thereof). For each distress type, severity level and density within a sample unit, a deduct value will be given according to the curves, Figures A-10 to A-24 in the Guideline. A total deduct value (TDV) will be obtained by summing all the deduct value for each distress. A corrected deduct value (CDV) will then be obtained from Figure A-25 in the Guideline. PCI for each sample unit is calculated as 100 – CDV. The PCI for the uniform section is the average of all sample units.

Calculation of the PCI for the section in this project uses weighted average method. For instance, there are two sample units, 130 and 131, in section 20. Sample unit 130 is 225 ft long with a PCI of 88. Sample unit 131 is 150 ft long with a PCI of 83. Weighted average PCI for section 20 is obtained as shown below:

$$Weighted\_Average\_PCI = \frac{(225 \times 88) + (150 \times 83)}{225 + 150} = 86$$

IMAGE DATA SETS

There are 12 folders containing all the images for each runway pavement. Each folder contains an entire survey of half of a lane and represents one pass of the data vehicle on the runway. The folders are given below.

Runway 8R:

2001-11-26, 12-07-20AM-8RA1; 2001-11-26, 12-11-48AM-8RA2;

2001-11-26, 12-17-36AM-8RB1; 2001-11-26, 12-24-55AM-8RB2;

2001-11-26, 01-21-03AM-8RC1; 2001-11-26, 01-28-13AM-8RC2;

2001-11-26, 12-33-57AM-8RD1; 2001-11-26, 12-39-18AM-8RD2;

2001-11-26, 12-48-43AM-8RE1; 2001-11-26, 12-55-15AM-8RE2;

2001-11-26, 01-03-02AM-8RF1; 2001-11-26, 01-14-07AM-8RF2

Runway 9L:

2001-11-25, 12-49-05AM-9LA1; 2001-11-25, 01-02-06AM-9LA2;

2001-11-25, 01-12-12AM-9LB1; 2001-11-25, 01-27-34AM-9LB2;

2001-11-25, 01-43-44AM-9LC1; 2001-11-25, 01-51-41AM-9LC2;

2001-11-25, 01-59-15AM-9LD1; 2001-11-25, 02-04-31AM-9LD2;

2001-11-25, 02-12-18AM-9LE1; 2001-11-25, 02-22-29AM-9LE2;

2001-11-25, 02-35-17AM-9LF1; 2001-11-25, 02-43-01AM-9LF2

Any two folders in the same line above contain images for one lane. For example, the folder with the ending 8RA1 means the first pass for lane A covering the first half of the lane, and 8RA2 means the second pass for lane A covering the remaining half of the lane. Due to an image can only capture 14 ft of the road, two passes has been made to capture all 25 ft wide of lane. The lane is therefore spliced into two folders, such as A1 and A2 folders, B1 and B2 folders, etc.

ANALYSIS RESULTS

Each distress type and severity level are recorded for every 25 ft fraction or 25 ft slab. For instance, 3L is recorded as a low severity longitudinal/transverse/diagonal crack. The number beside 3L indicates the image that contains such crack. For example, 3L-16a means that the crack is found in image cap000016.jpg of folder 1. Distress 3L-16b means that the crack is found in image cap000016.jpg of folder 2.

The PCI result is given in tables below. Tables 1, 2 and 3 contain results for Runway 8R and Tables 4, 5, and 6 contain results for Runway 9L. Figures 7 and 8 demonstrate visual presentation of PCI values for the sections of the two the runways.

Table 1: Left Outboard (lane A, B), 8R

Section	Sample Unit	PCI	Rating
10	100	72	V. Good
11	101 - 102	76.5	V. Good
12	103 - 106	71.2	V. Good
13	107 - 111	74	V. Good
14	112 - 114	75.7	V. Good
15	115 - 118	82.6	V. Good
16	119 - 122	89.5	Excellent
17	123 - 124	85.8	Excellent
18	125 - 132	84.5	V. Good
19	133	85	Excellent
20	134 -135	86	Excellent
21	136	75	V. Good

Table 2: Keel (lane C, D), 8R

Section	Sample Unit	PCI	Rating
30	300	77	V. Good
31	301 - 302	68.5	Good
32	303 - 306	71.5	V. Good
33	307 - 311	65.8	Good
34	312 - 314	66.2	Good
35	315 - 318	66.3	Good
36	319 - 322	72.2	V. Good
37	323 - 324	69.6	Good
38	325 - 332	60.6	Good
39	333	66	Good
40	334 - 335	78	V. Good
41	336	85.5	Excellent

Table 3: Right Outboard (lane E, F), 8R

Section	Sample Unit	PCI	Rating
50	500	83	V. Good
51	501 - 502	70.5	V. Good
52	503 - 506	64	Good
53	507 - 511	67.8	Good
54	512 - 514	80.3	V. Good
55	515 - 518	77.4	V. Good
56	519 - 522	76.4	V. Good
57	523 - 524	77.2	V. Good
58	525 - 532	89.4	Excellent
59	533	82	V. Good
60	534 - 535	95.8	Excellent
61	536	87.5	Excellent

Table 4: Left Outboard (lane A, B), 9L

Section	Sample Unit	PCI	Rating
10	100	100	Excellent
11	101 - 106	96.4	Excellent
12	107 - 110	96.2	Excellent
13	111 - 114	100	Excellent
14	115	98	Excellent
15	116 - 117	99.5	Excellent
16	118	100	Excellent
17	119 - 120	100	Excellent
18	121 - 123	87.3	Excellent
19	124 - 128	98.4	Excellent
20	129 - 131	96.6	Excellent
21	132 - 133	100	Excellent
22	134 - 136	92.6	Excellent
23	137 - 142	92.2	Excellent
24	143 - 144	95.5	Excellent
25	145	100	Excellent

Table 5: Keel (lane C, D), 9L

Section	Sample Unit	PCI	Rating
30	300	96	Excellent
31	301 - 306	87.3	Excellent
32	307 - 310	78.6	V. Good
33	311 - 314	77.4	V. Good
34	315	73.5	V. Good
35	316 - 317	75.8	V. Good
36	318	79	V. Good
37	319 - 320	90.1	Excellent
38	321 - 323	91	Excellent
39	324 - 328	84.5	V. Good
40	329 - 331	78.2	V. Good
41	332 - 333	78	V. Good
42	334 - 336	78.7	V. Good
43	337 - 342	85.2	Excellent
44	343 - 344	82.5	V. Good
45	345	97	Excellent

Table 6: Right Outboard (lane E, F), 9L

Section	Sample Unit	PCI	Rating
50	500	100	Excellent
51	501 - 506	97.2	Excellent
52	507 - 510	90.6	Excellent
53	511 - 514	88.6	Excellent
54	515	88.5	Excellent
55	516 - 517	90.3	Excellent
56	518	98	Excellent
57	519 - 520	98	Excellent
58	521 - 523	87.2	Excellent
59	524 - 528	97.3	Excellent
60	529 - 531	96.3	Excellent
61	532 - 533	100	Excellent
62	534 - 536	97.7	Excellent
63	537 - 542	100	Excellent
64	543 - 544	95	Excellent
65	545	100	Excellent

There are some limitations of the procedure. The collected images are 2-dimensional, some distresses are being ignored because it cannot be determined from the images. For instance, blow up, pumping and settlement/faulting distresses could not be accurately identified and therefore, were ignored. Quality of the images affect the rating as well. Tire marks made some images very dark and therefore some distresses may not be visible.

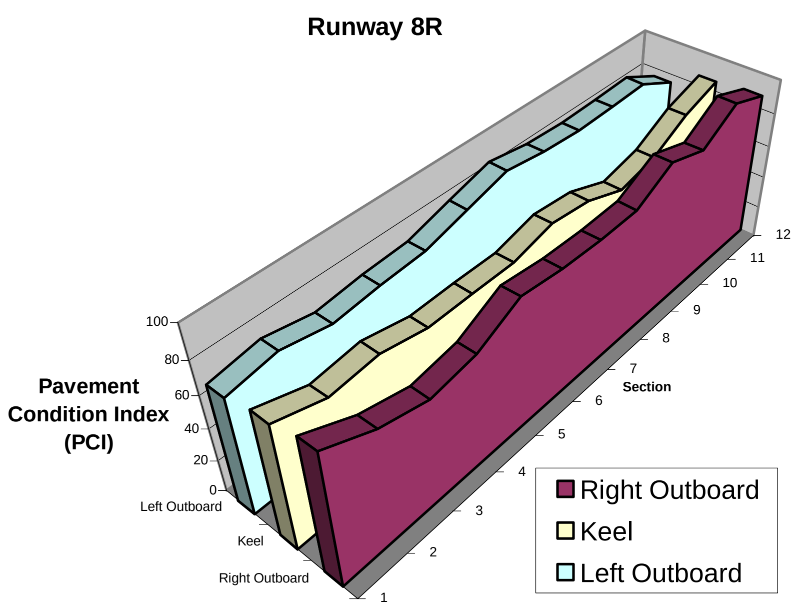

Figure 7 Visual presentation of Runway 8R

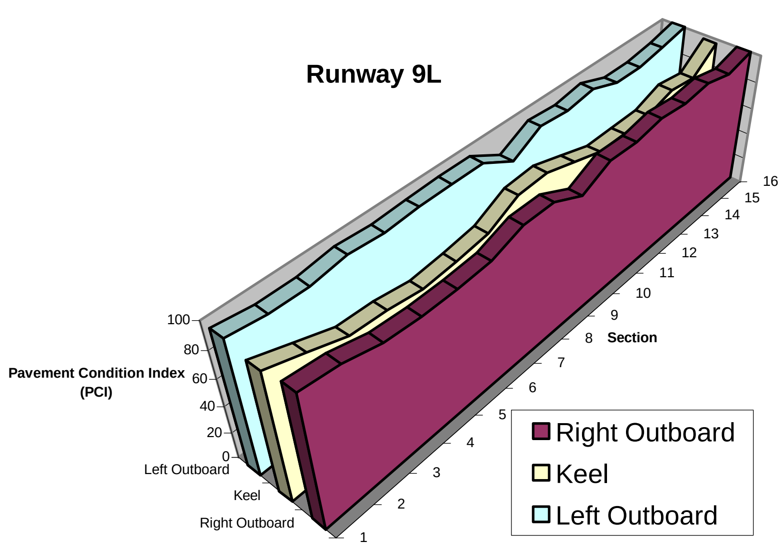

Figure 8 Visual presentation of Runway 9L

CONCLUSION

When the researchers started this project several years back, the level of difficulty and problems encountered by many other developers cast uncertainty about whether the effort would come to fruition. We are confident now that solution to the problem of automating distress survey is finally at hand. The challenge of using the automated system for airport survey is to identify and classify distresses based on the PAVER approach. Distresses in PAVER include defects including cracks and many other condition problems. Automation of condition survey of airport pavements is a primary goal of out future research.

REFERENCES

AASHTO, Standard Practice for Quantifying Cracks in Asphalt Pavement Surface, AASHTO Designation: PP44-00, 2000

FAA AC:150/5380-6, "Guidelines and Procedures for Maintenance of Airport Pavements"

Paterson, William D. (1994). "Proposal of Universal Cracking Indicator for Pavements", Transportation Research Record 1455, pp. 69-76, Washington, D.C.

Texas Department of Transportation, Pavement Management Information System Rater's Manual, Fiscal Year 1999

Wang, K.C.P. "Design and Implementation of Automated Systems for Pavement Surface Distress Survey", ASCE Journal of Infrastructure Systems, Vol.6, No1, March, pp. 24-32, 2000