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AUTOMATED PAVEMENT EVALUATION SYSTEM FOR PAVEMENT DISTRESS ASSESSMENT

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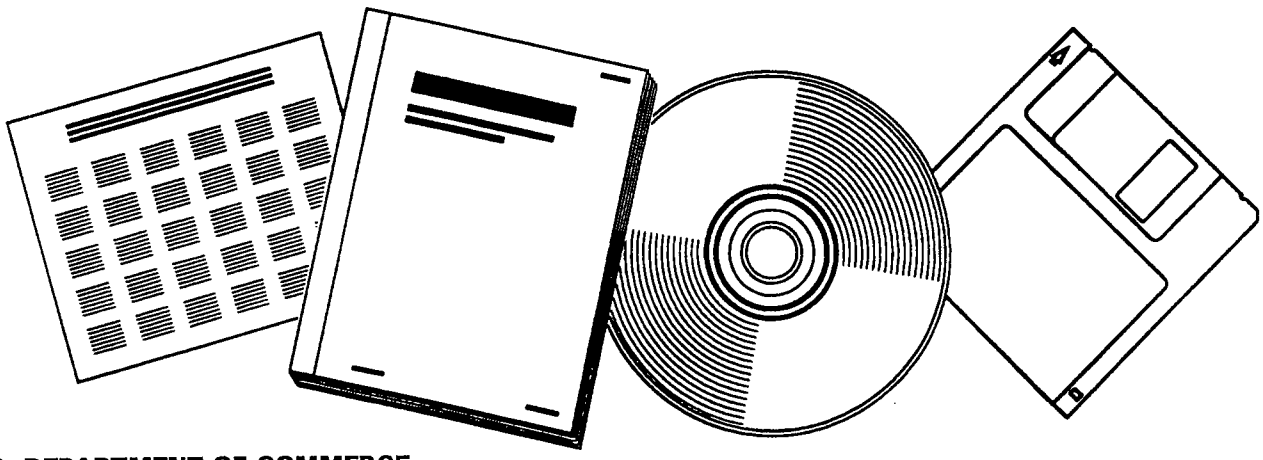

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AUTOMATED PAVEMENT EVALUATION SYSTEM FOR PAVEMENT DISTRESS ASSESSMENT

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16. Abstract

This paper describes work performed for the Connecticut Department of Transportation (ConnDOT) to automate the evaluation of pavement distress images. In 1983, the ConnDOT began developing a pavement management system for state-maintained highway. The basis for the pavement rating system is ConnDOT's photologging system in which a series of photographs of the pavement surface is stored on laser videodiscs and later used to assign pavement condition scores for maintenance purposes. The rating scheme currently being used by ConnDOT is based on manual evaluation in which raters view all sections of pavement images on a monitor and count distress features. This manual rating process is extremely time consuming and tedious.

The goal of this work was the development of an automated and integrated system for the evaluation of pavement distress condition. A new distress segmentation algorithm was developed to isolate distress features from images (such as the ConnDOT images) that have excessive noise and significant variation in contrast level. The system developed from this research produced an output which indicated the presence or absence of distress features on the image at the end of the image processing procedures.

The overall system environment as well as integration tasks are discussed in this report.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	mililitres	mL
gal	gallons	3.785	Litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

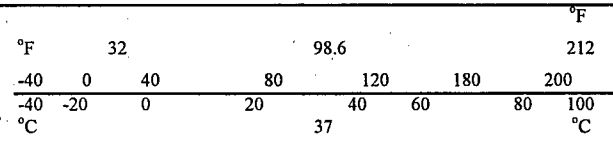
NOTE: Volumes greater than 1000 L shall be shown in m^3

		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
^0F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	^0C

* SI is the symbol for the International System of Measurement

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
^oC	Celcius temperature	1.8C+32	Fahrenheit temperature	^oF



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I Introduction

Highway systems deteriorate due to exposure to traffic loading and environmental factors. In order to keep highways in good condition, maintenance and repair strategies must be based on an informed knowledge of current pavement conditions. Visual observation of pavement distress is the most common method for monitoring and evaluating pavement surface conditions. This has been traditionally performed by trained engineers who walk or drive along the road and count the distresses. However, this visual survey method takes too much time and effort, is too costly, and is often dangerous due to exposure to traffic.

Advances in video technology now make it possible to capture and record pavement images on high quality media to create a permanent visual record of the actual pavement condition. Over the past few decades, various types of photologging equipment have been devised by agencies to collect and classify precisely all distresses which may influence pavement performance. The ConnDOT pavement photologging system is one of several that have been introduced. The vehicles used for ConnDOT photologging system measure pavement roughness, highway geometrics, and records other useful numerical data such as location, date, time, and vehicle speed. Pavement surface images are also recorded to provide a permanent visual record of the actual pavement condition.

Once the images are recorded, they must be evaluated and rated by pavement management personnel to determine present pavement condition, and establish priorities for improvements. The rating scheme that is currently being used by ConnDOT is based on manual evaluation in which raters view all sections of pavement images on a monitor and count distress conditions. This manual rating process is extremely time-consuming

and tedious; the DOT estimates that it takes up to four months to complete the ratings even though the fraction of the total pavement surface actually examined is only about five to ten percent. Distress identification and interpretation also varies among raters, producing inconsistent pavement condition rating scores.

There is a need for an improved method of pavement evaluation that would allow for more effective use of the highly sophisticated method of data storage that is represented by the DOT's laser video disk system.

The goal in this research was the development of an automated and integrated system for the evaluation of pavement distress condition. In this project, the scope was limited to develop a system that could be used to indicate the presence or absence of distress features on the image. However, it is felt that the image processing algorithm and integration tasks developed from this research can be used as the framework for a comprehensive pavement evaluation system.

II Project Overview

The system developed in this project was designed on the assumption that it would eventually replace the current ConnDOT method of manually rating laser-video disk images. A schematic diagram of the approach used in this project is shown in Figure 1. The system was developed by conducting the following tasks; system development, system integration, system validation, system refinement, and system demonstration. The remainder of this section presents an overview of the research approach that is depicted in Figure 1.

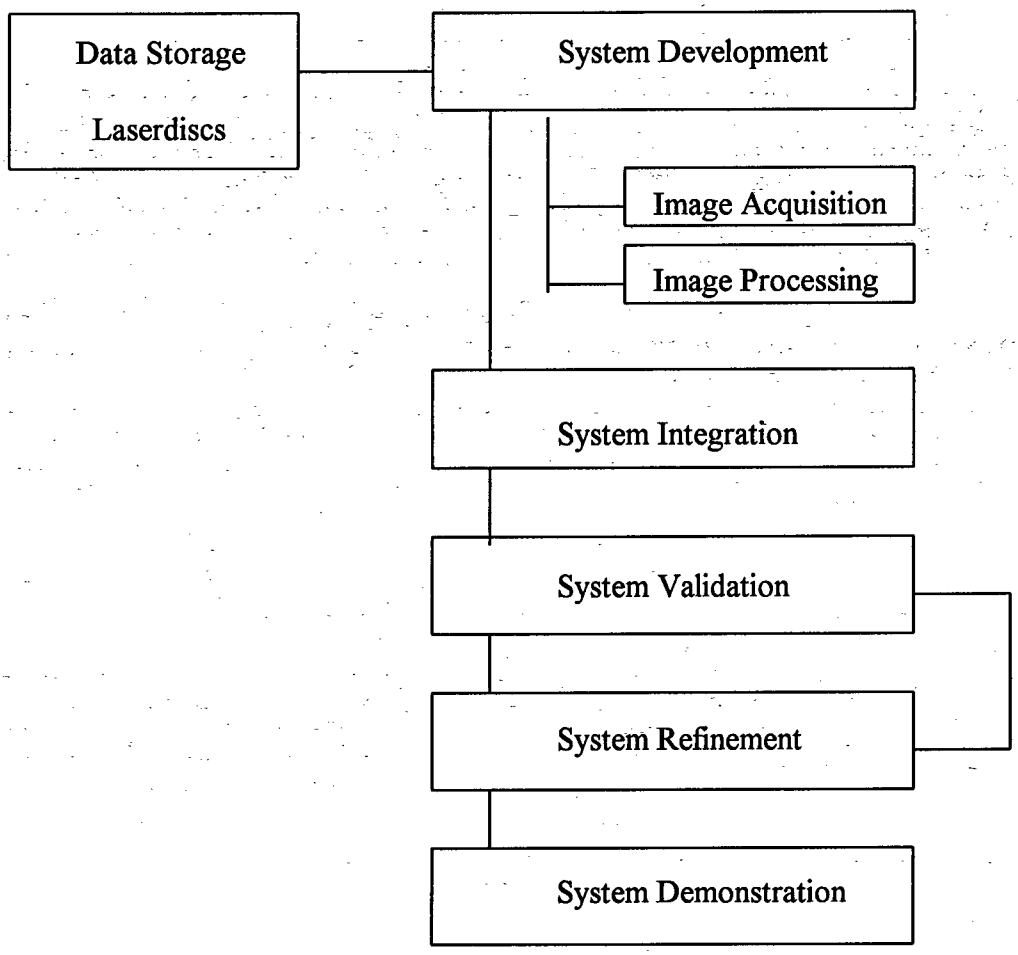


Figure 1: Schematic Diagram of Research Approach

2.1 System Design

The first task was the selection of a suitable set of image processing software and hardware. Since the automated pavement evaluation system requires extensive use of variable image processing routines, a highly sophisticated image processing software was needed. We chose an image processing software called Khoros as our image processing tool. Khoros is a software integration and development environment that emphasizes information processing and data exploration. It also provides an extensive collection of image processing routines as well as multidimensional data manipulation operators including pointwise arithmetic, statistic calculations, data conversions, histograms, and size operators. The visual programming environment provides graphical icons which can be interactively manipulated according to some specific spatial grammar for program construction (Golin, et al., 1990).

For the hardware, a Pentium-based personal computer equipped with image digitizer board was used. This personal computer had a CPU with 100 MHZ speed, 32MB size of RAM, and 2.0 Giga bytes of hard disk spaces. An additional 64MB of virtual memory was added in order to speed up the processing time. Since the image processing software (Khoros) requires the Unix environment, a Linux operating system was installed on the PC.

2.2 Data Selection

The ConnDOT photolog pavement images are captured using a 35mm movie camera which is mounted in a van traveling at speeds of 40 to 50 mph. The film is exposed at intervals of 0.01 mile (or 52.8 feet). The total length of state-maintained roads

in Connecticut is 7,700 bi-directional miles, therefore, it takes a total of 770,000 images to represent the entire network.

In developing our image processing algorithms, we sampled images from interstate highways, arterial roads and state-maintained local roads. The reasons for sampling images from different roads are that (1) each of these types of roads is characterized by different distress types due to differences in traffic loading and pavement strength, and (2) images for each type of road will have different non-distress features (for example, images of local roads will contain more shadows from trees and overhead power lines than those of interstate highways, See Figure 2).

Also, images recorded in different years(1987-1994) were sampled since the resolution differs from year to year.

The images chosen were divided into the following four categories to effectively develop the image processing algorithm : (1) images with no distress and no shadows, (2) images with no distress but with shadows, (3) images with distress but with no shadows, and (4) images with distress and shadows.

In developing the image processing algorithm, approximately 40 images from each of the four categories above was selected as the initial data-set. A larger sample size could not be used at that stage of the study due to data storage limitations. However, the completed system was tested with a larger number of images once the system integration was completed.

The details of the image processing algorithm will be discussed in Chapter 3.

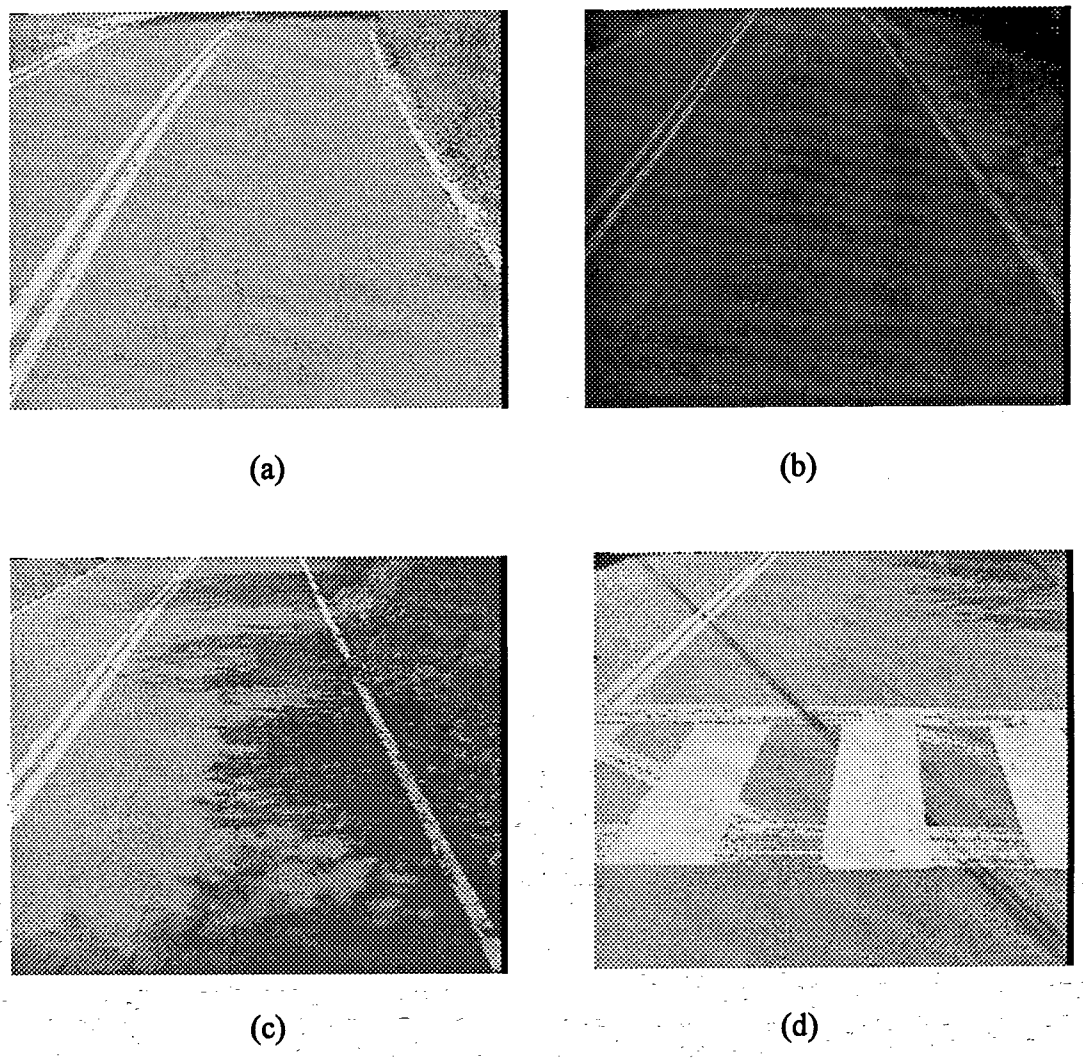


Figure 2: Typical ConnDOT Pavement Images; (a) Image With High Contrast, (b) Image With Low Contrast, (c) Image With Tree Shadows, (d) Image With Paint Striping and Shadow From Overhead Power Lines

2.3 System Development

The development of the image processing system was the primary focus of this project. The goal in processing the pavement images is to isolate the distress features from the remainder of the image. This is achieved through image segmentation; the end product of image segmentation is a binary image in which the distress features are represented as black on a white background.

Previous studies have indicated that automatic segmentation is the most difficult aspect of developing an automated pavement evaluation system (Koutsopoulos 1991, Kaseko, et al., 1992, Lee 1993). This is due to the fact that the contrast level of the distress features shows no consistent pattern relative to that of the remainder of the image. In addition, the ConnDOT images pose additional difficult challenges due to excessive noise and large variability in contrast due to shadows.

The image processing procedure for the ConnDOT images was designed to address the task of segmenting the distress features even in the presence of shadows and variability in contrast levels. The system was developed to work for each of the four categories of images defined in the previous section. Once sufficient confidence had been acquired regarding the adequacy of the image processing algorithm, the next phase, system integration, was undertaken.

2.4 System Integration

The goal of this task was to develop a graphical user interface for integration of the various modules of the system so that processing can proceed smoothly without manual intervention. Once the image processing procedure was developed and conducted, the raw images from the laserdisc, intermediate files created while processing, and final binary images had to be saved on a hard disk. Therefore, a large number of samples could not be used with stand alone image processing module. In this task, the intermediate files that were produced from the image processing procedure were removed. Hence, a great amount of time and computer resources were saved at this stage.

In addition, this task allowed for the examination of a larger number of images during testing and validating.

A computer code was written using TCL/TC scripts to provide a user-friendly graphical interface. This code controlled both hardware (e.g., laserdisc player) and software (e.g., Khoros-Pro and programs for image acquisition). Once this integration task was completed, a fully integrated tool was obtained that had capability of (1) taking specific section of images directly from the laserdisc, (2) processing the image to isolate the distress features, and (3) reporting on the presence or absence of a distress on that image.

2.5 System Validation

Once the all four of above tasks was finished, the system was tested with new randomly selected images from the laserdiscs. Following this validation stage, the system was refined in order to give more robust performance so that it could handle all foreseeable distress configurations.

III Development of Image Processing System

The primary goal in developing the image processing system was to isolate the distress features from the remainder of the image. This was achieved through image segmentation; the end product of image segmentation was a binary image in which the distress features were represented as black on a white background.

The structure for the image processing system can be roughly outlined as follows.

- **Image processing component** to process the image and separate potential regions of interest from the background
- **Pattern recognition component** to determine the absence or presence of cracks, and identify the major distress types.

The ConnDOT images posed many difficult challenges due to excessive noise and large contrast variability as can be seen in Figure 2. The image processing procedure developed from this research constituted image preprocessing, image segmentation, and logistic screening for effective analysis of the ConnDOT images. The pattern recognition procedure was also initiated to determine the absence or presence of cracks. The issue of distress identification and quantification was not addressed in this phase of the project. The details of the image processing tasks are discussed in the following sections.

3.1 Image Processing

Previous studies have indicated that automatic segmentation is the most difficult aspect of developing an automated pavement evaluation system (Koutsopoulos 1991, Kaseko, et al., 1992, Lee 1993). This is due to the fact that the pixel intensity of the distress features shows no consistent pattern relative to that of the remainder of the image. In general, the pixel intensities of the distress features are lower than that of other features

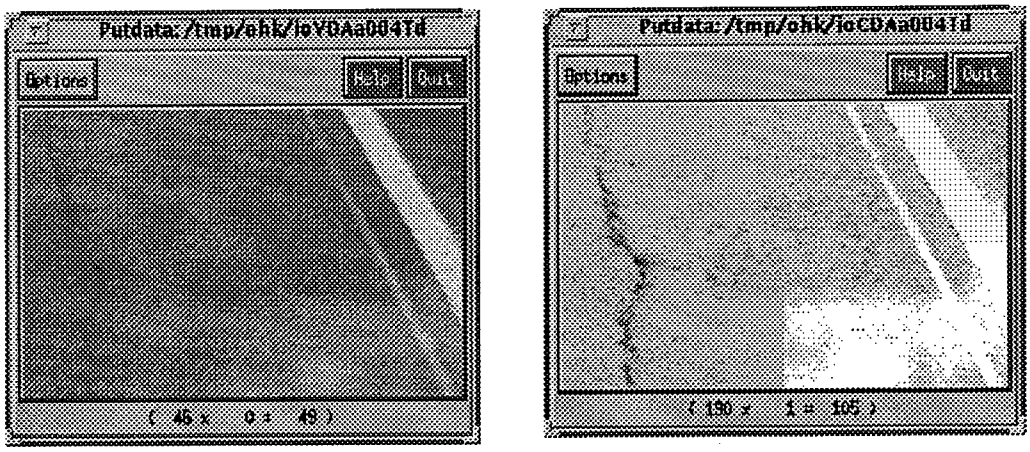
in the image. Moreover, the histogram of images with distress features may be either unimodal or bimodal. In the case where the histogram is unimodal, it is difficult to choose an appropriate threshold level for effectively separating the distress features from the background (Ritchie 1991). In addition, many of the ConnDOT images contain shadows, and such images with shadows frequently show bimodal distribution which mimics the bimodal distribution of some images with distress features. This presents an additional problem in determining a consistent threshold value which will work for all images.

The image processing procedure for the ConnDOT images was designed to address the task of segmenting the distress features even in the presence of shadows and variability in contrast levels. It involves an iterative clipping algorithm to obtain a consistent relationship between the distress features and the background. This is done by reducing the range of pixel values in the image. The iterative clipping algorithm also incorporates a logistic screening model that is designed to minimize problems with images that contain extreme and abrupt changes in contrast level. Each of these processes is discussed below.

3.1.1 Image Preprocessing

The analysis area (which is 600 by 180 pixels) was devided into eight(8) tiles of 150 by 90 pixels. This approach was taken because the range of pixel intensities in the full image is too large for effective analysis. In general, the pixel values in each tile are more homogeneous, and thus, the tile presents a less difficult environment for developing an effective segmentation method.

The first step of the iterative clipping procedure is to calculate the mean pixel



(a) (b)

Figure 3: Example of Image after Preprocessing; (a) Original Image
(b) Image after Preprocessing

intensity of the tile image. This mean is then used as the clipping value. In other words, all pixel values above the clipping value are set to the clipping value while pixel values below the clipping value are left unchanged. This process cuts in half the range of contrast level in the image. However, pixels with low intensity, which tend to represent distress features, are left unaffected by this process. Therefore, the clipping process eliminates much of the background without affecting the distress features (see Figure 3).

3.1.2 Image Segmentation

After the first clipping stage, a new mean and standard deviation are calculated. The clipping process is repeated using a new clipping value which is given by the following equation:

$$C^n = \mu^{n-1} - (1.2 \times S^{n-1})$$

where,

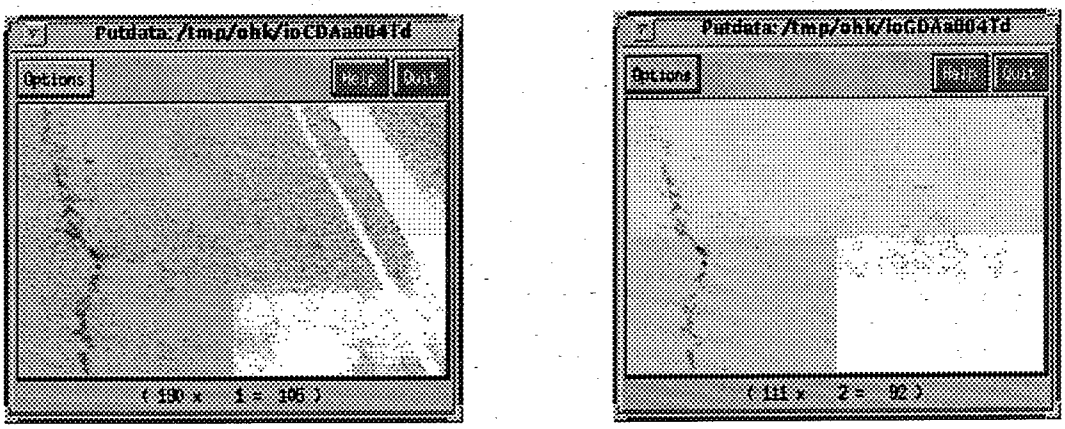
C^n is the new clipping value at the n^{th} iteration;

μ^{n-1} is the running mean value at the n-1^{th} iteration; and,
S^{n-1} is the running standard deviation value at the n-1^{th} iteration.

This clipping value was determined to be the lowest value that could safely be used which would still be greater then most of the pixel values in the distress features. Once the clipping is done using this value, more of the noise in the image (including the shadows) will be suppressed into the background (See Figure 4).

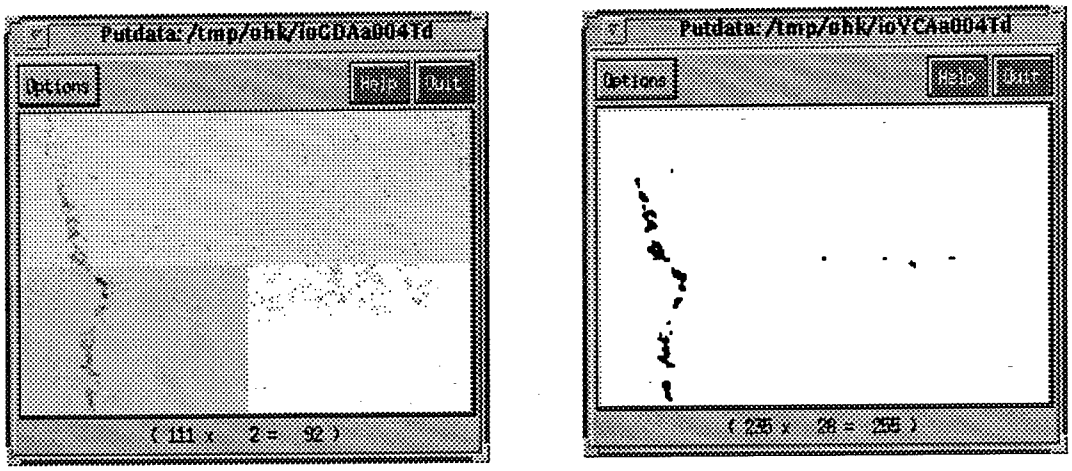
This clipping process is repeated until the difference between the clipping value and the mean value after clipping is equal to or less than 0.3 on the gray level scale. In general, once this termination point has been reached, most features other than the distresses will have been suppressed into the background. Any additional clipping beyond this point will tend to eliminate significant portions of the distress features.

The use of this termination criteria also results in a relatively consistent relationship between the final clipping value and the pixel values of the distress features. In other



(a) (b)

Figure 4: Example of Image after Iterative Clipping; (a) Image after Preprocessing (b) Image after Iterative Clipping



(a) (b)

Figure 5: Example of Image after Thresholding; (a) Image after Iterative Clipping (b) Image after Thresholding

words, the pixel values of the distress features are generally at a predictable level below that of the overall mean pixel values in the tile.

Therefore, an automatic threshold value can be set for segmenting the distress features from the background. The threshold level that was chose was five(5) gray-scale below the mean (see Figure 5). If this threshold value is adjusted upwards, the tile image will contain too much noise. Conversely, if it is adjusted downwards, some portion of the distress will be lost.

3.1.3 Logistic Screening

The system works very well for most images; as can be seen in Figure 6-(a), it easily isolates the distress features for images without shadows. It also works well for most images which contain shadows (see Figure 6-(b)). However, for a small number of images, the system failed - picking up a significant amount of noise in parts of some types

of shadows (see Figure 6-(c)). The evaluation of this problem showed that the images for which the system failed all had certain identifiable characteristics.

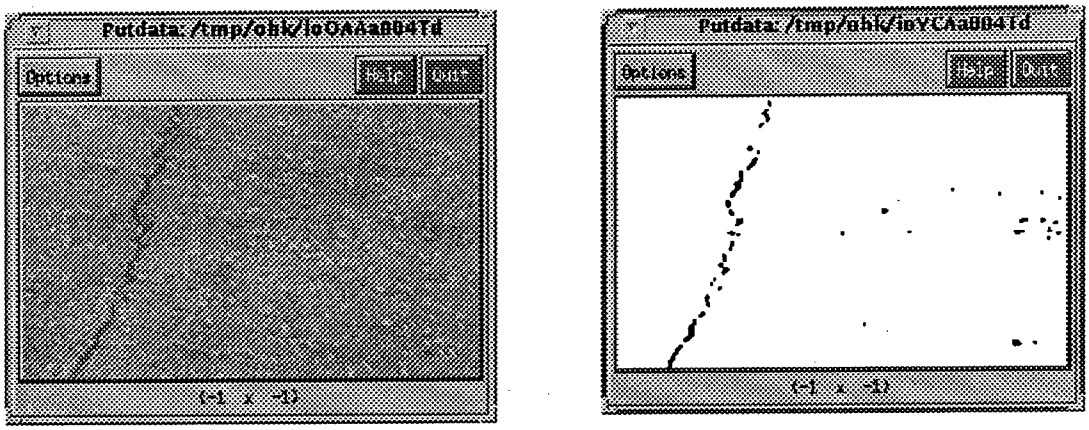
These images tended to have fairly sizable areas of shadows (30 to 60 percent of the tile) and the shadows were characterized by extreme variation in contrast level. In other words, the contrast level within shadow varied so that the pixel values of portions of the shadow were significantly lower than that of the rest of the shadow. Since accurate segmentation is virtually impossible for such images, a method was developed to identify images with these variable contrast features. Once these images are identified, they are eliminated from further consideration. In other words, these images are treated as if they contain no distress features. This will result in some mis-categorization since some of these images will, in fact, contain distress features.
However, any error introduced by this approach will be small compared to the errors that would have resulted from faulty segmentation of this type of images.

The basis of this identification is a logistic regression model which uses statistical parameters such as mean, standard deviation, skewness, maximum, and minimum value for the original and final images. The equation of logistic regression model is given as follows:

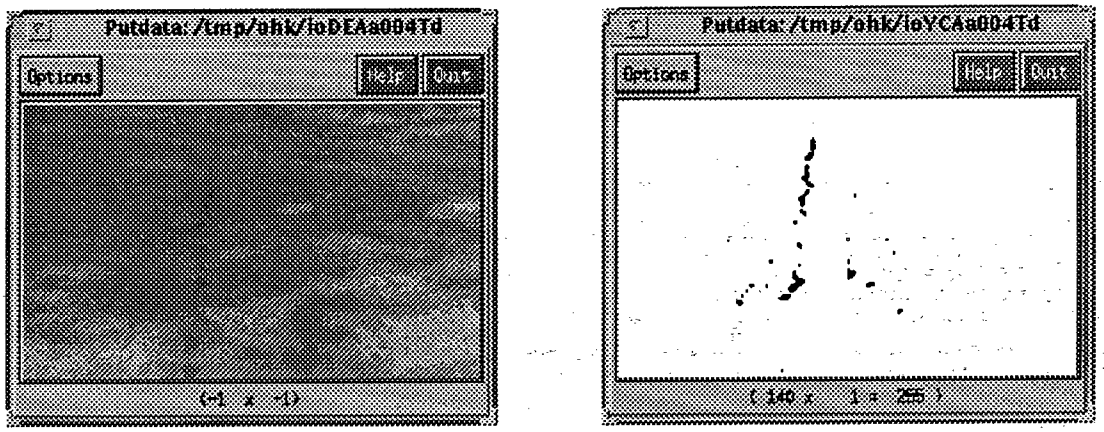
Probability (Image with variable shadow pixel intensities) = $1 / (1 + e^{-Z})$

where, Z is a function of mean, standard deviation, skewness, maximum, and minimum value before and after clipping procedure.

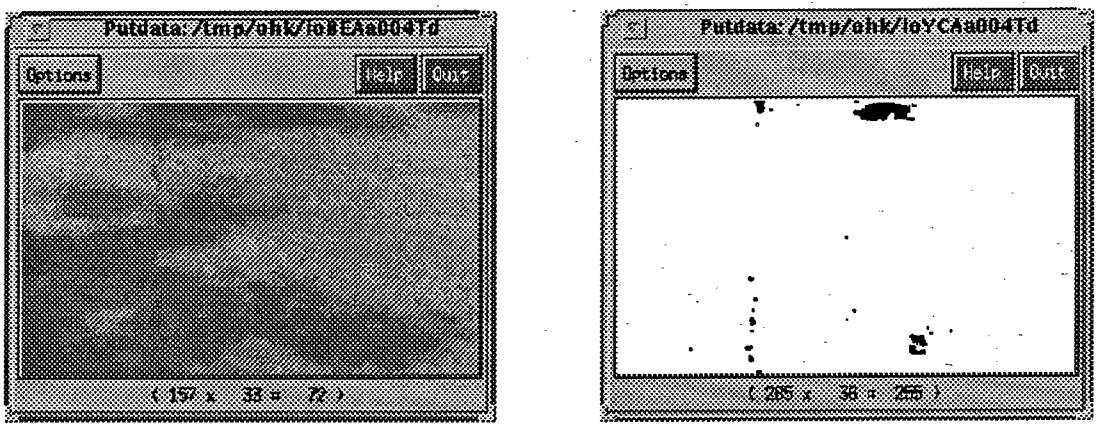
This logistic regression equation is used to calculate the probability of whether or not a given image falls into a category of having a variable shadow pixel intensity level. The probability calculation is based on the statistical parameters shown in the equation.



(a) Image With No Shadow and Distress



(b) Image With Shadow and Distress



(c) Image With Shadow and Distress

Figure 6: Examples of Original and Binary Image After Terminating Iterative Clipping Procedure (i.e. Combination of 4 tile images: 300 * 180 pixels)

The relative value of these statistical parameters before and after clipping is dependent on the nature of the image. For example, images with very large contrast show large changes in mean, maximum, and standard deviation. Conversely, images with distress and no shadows show relatively small changes in these parameters.

Based on an assessment with 168 individual tiles from 42 images, the use of iterative clipping combined with logistic screening increases the prediction accuracy from 85 percent to 90 percent.

IV System Integration

The goal of system integration was to provide a user-friendly graphical interface so that the pavement surface assessment could be easily and efficiently conducted. This was achieved by the integration of the image acquisition module with the image processing procedure. The system was designed so that the user must first select the desired section(s) of the roadway including route name, direction, recorded year, and start mileage from the inventory of state maintained roadway. Then, the system automatically finds the corresponding laserdisc, grabs the image(s), performs image processing to isolate the distresses, predicts the presence or absence of distress features on the image, and produces an output file which summarizes the results. More detail description of integration task is described below.

4.1 Image Acquisition

The role of image acquisition is to retrieve the image data from the data storage (e.g., laserdisc) and place it into memory on the PC. An image grabbing board called MV-1000 along with MV-1350 daughter card manufactured by Mutech Corps were attached to the PCI board on the personal computer to capture images from the laserdisc player. Those cards were also connected to a serial port on a laser disc player with a communication cable. Using the library provided by Mutech Corps, a C code was written to control the laser disc player from the personal computer. With this code in place, the user can define a section of roadway from the graphical user interface, and the laserdisc player automatically finds the corresponding image(s), and sends the binary information to the computer.

4.2 UPAS

A computer code called UPAS (University of Connecticut Pavement Assessment System) was written using Tcl/tk scripts. The role of UPAS was to integrate and control both hardware (e.g., image grabbing board, laserdisc player) and software (e.g., Khoros image processing software). As a result, the user could select a particular location of the road or section(s) of the roadway from the drop-menu bar. Once the desired section(s) of the roadway was selected by the user, image processing procedure was performed automatically.

The resulting binary image after image processing could be seen on a monitor, and summary output including useful information such as laserdisc number, year, date, route name, route direction, starting mileage, frame number, and results from image processing was saved to a file (See Table 1).

Table 1: Sample Output from UPAS

{Route ID} Year Disk Start-Mile Start-Frame Adjustment Logging Frame Khoros-Output
{1993 Route-630 North} 1993 25 0.0 5 26539 F 26744 "10506: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 26944 "10748: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 27144 "10968: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 27344 "11189: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 27544 "11418: Clean"

V System Validation

In order to validate the performance of the system, results generated by the system were compared against an inventory of distresses generated by a manual visual survey of the same video data. The databases created from the system consist of numerical information such as route ID, year, disk number, start mileage, frame number, and information about absence or presence of crack determined by the system.

Two separate data sets were used in conducting the validation for the system. The first data-set contained 4 test sections of a half mile in length, and a second data-set contained frames at 200 frame number interval from four different laserdiscs. These sections are selected from local state-maintained roads recorded in 1989, and 1993 by the ConnDOT photologging vehicle.

Table 2 shows the summary of validation results for a data set of 712 images. Of the 303 images with distress features, the system correctly categorized 262 of the images has having distress features. However, 41 out of the 303 images with distress features were incorrectly categorized. In general, these 41 images had very fine cracks which were eliminated by the iterative clipping process. This performance could be improved by changing the threshold level; however, this would then add additional noise to all the images.

Of the 409 distress free images, the system correctly categorized 378 images as containing no distress features. However, 31 of 409 images were mis-categorized. This type of error occurred when images were encountered with variable shadows.

The overall results for 712 images shows a 90 % of accuracy in predicting the absence or presence of cracks. This result is almost identical to the results obtained in the preliminary assessment rated with 168 individual tiles from 42 images.

Table 2: System Validation with 712 Sampled Images.

Observed	Predicted		Total	Accuracy %
	Distress	No Distress		
Distress	262	41	303	86.5
No Distress	31	378	409	92.4

Appendix A contains a more detailed description of the comparison study.

VI Conclusions and Recommendations

6.1 Conclusions

The purpose of this project was to develop an automated pavement distress evaluation system for the ConnDOT photologging program. The ConnDOT images pose difficult image processing challenges due to excessive noise and large variability in contrast levels. Many different algorithms have been proposed by researchers for processing images of pavement surfaces. However, these methods do not work well for images with the types of problems that are seen on the ConnDOT images.

In this project, an automated pavement evaluation system which is robust enough to process images with both noise and contrast variation problems was developed. This system was based on tcl/tk and C code for integration and Khoros visual programming code for image processing. Image processing procedure used iterative clipping to obtain a consistent relationship between the distress features and the background. In addition, logistic regression screening was used to minimize problems with images that contain extreme and abrupt changes in contrast level.

The system showed a 90% accuracy for predicting the presence or absence of distress features on the image when tested for 712 ConnDOT images. The output from this system is suitable for use as part of a comprehensive system for further analysis of distress identification and quantification.

6.2 Recommendations for Future Research

Results from the validation of the system establish the fact that the image processing algorithm and system integration work should be suitable for use as part of a comprehensive system for further analysis of distress identification and quantification.

However, more work needs to be done in order to obtain a robust and fully automated pavement evaluation system. Some of the issues that need to be addressed during future research in this area are as follows. First, the pattern recognition component needs to be developed and integrated to quantify the extent (lengths, widths, and areas) of the various distresses. The binary images produced from the system provide accurate visual distress information. Suitable parameters from these binary images should be found to identify the distress type and severity. Second, issues of geometric distortion due to the windshield views should be addressed in order to provide more accurate distress information. The effect of windshield-view distorts the scale of the image and is a major concern when determine the lengths and orientation of cracks. It may be desirable to transform this image to correct the distortion.

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Appendix A Validation Data

The following data were created by the system. Two separate data sets were used when conducting the validation for the system. The first data set contained 4 test sections of half mile in length, and the second data set contained frames at 200 frame number interval from four different laserdiscs. These results were compared against an inventory of distresses generated by a manual visual survey of the same video data.

{Route ID} Year Disk Start-Mile Start-Frame Adjustment Logging Frame Khoros-Output

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{Route ID} Year Disk Start-Mile Start-Frame Adjustment Logging Frame Khoros-Output

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{1989 Route-197 East} 1993 25 0.0 5 26539 F 44144 "10595: Clean"
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{1989 Route-197 East} 1993 25 0.0 5 26539 F 49344 "15680: Clean"
{1989 Route-197 East} 1993 25 0.0 5 26539 F 49544 "15733: Crack"
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{1989 Route-197 East} 1993 25 0.0 5 26539 F 52144 "18217: Clean"
{1989 Route-197 East} 1993 25 0.0 5 26539 F 52344 "18416: Clean"
{1989 Route-197 East} 1993 25 0.0 5 26539 F 52544 "18616: Clean"
{1989 Route-197 East} 1993 25 0.0 5 26539 F 52744 "18816: Clean"
{1989 Route-197 East} 1993 25 0.0 5 26539 F 52944 "19016: Clean"

{Route ID} Year Disk Start-Mile Start-Frame Adjustment Logging Frame Khoros-Output

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{1993 Route-95 North} 1993 25 0.0 5 26539 F 26744 "19336: Clean"
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{1993 Route-95 North} 1993 25 0.0 5 26539 F 27144 "19530: Crack"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 27344 "19743: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 27544 "19972: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 27744 "20199: Clean"
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{1993 Route-95 North} 1993 25 0.0 5 26539 F 28144 "20523: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 28344 "20722: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 28544 "20928: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 28744 "21136: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 28944 "21349: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 29144 "21562: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 29344 "21768: Clean"

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{1993 Route-95 North} 1993 25 0.0 5 26539 F 29744 "22169: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 29944 "22417: Crack"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 30144 "22623: Clean"
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{1993 Route-95 North} 1993 25 0.0 5 26539 F 30944 "23456: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 31144 "23655: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 31344 "23854: Clean"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 31544 "24062: Clean"
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{1993 Route-95 North} 1993 25 0.0 5 26539 F 52744 "10067: Crack"
{1993 Route-95 North} 1993 25 0.0 5 26539 F 52944 "10266: Clean"

{Route ID} Year Disk Start-Mile Start-Frame Adjustment Logging Frame Khoros-Output

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{1993 Route-115 North} 1993 25 0.0 5 26539 F 27144 "1904: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 27344 "2155: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 27544 "2384: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 27744 "2611: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 27944 "2824: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 28144 "3023: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 28344 "3236: Clean"
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{1993 Route-115 North} 1993 25 0.0 5 26539 F 33744 "7715: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 33944 "7855: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 34144 "8076: Clean"
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{1993 Route-115 North} 1993 25 0.0 5 26539 F 34744 "8719: Clean"
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{1993 Route-115 North} 1993 25 0.0 5 26539 F 42144 "15750: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 42344 "15956: Clean"
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{1993 Route-115 North} 1993 25 0.0 5 26539 F 42744 "16370: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 42944 "16576: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 43144 "16789: Clean"
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{1993 Route-115 North} 1993 25 0.0 5 26539 F 43544 "17107: Clean"
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{1993 Route-115 North} 1993 25 0.0 5 26539 F 43944 "17419: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 44144 "17640: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 44344 "17846: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 44544 "18066: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 44744 "18288: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 44944 "18596: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 45144 "18809: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 45344 "19022: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 45544 "19237: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 45744 "19406: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 45944 "19619: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 46144 "19853: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 46344 "20022: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 46544 "20231: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 46744 "20473: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 46944 "20672: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 47144 "20878: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 47344 "21084: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 47544 "21307: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 47744 "21513: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 47944 "21719: Clean"

{1993 Route-115 North} 1993 25 0.0 5 26539 F 48144 "21939: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 48344 "22108: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 48544 "22390: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 48744 "22596: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 48944 "22801: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 49144 "22919: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 49344 "23155: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 49544 "23430: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 49744 "23629: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 49944 "23835: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 50144 "24062: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 50344 "24284: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 50544 "24490: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 50744 "24601: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 50944 "24835: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 51144 "25035: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 51344 "25272: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 51544 "25507: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 51744 "25560: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 51944 "25780: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 52144 "26007: Crack"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 52344 "26237: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 52544 "26436: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 52744 "26649: Clean"
{1993 Route-115 North} 1993 25 0.0 5 26539 F 52944 "26869: Clean"

{Route ID} Year Disk Start-Mile Start-Frame Adjustment Logging Frame Khoros-Output

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{1993 Route-630 North} 1993 25 0.0 5 26539 F 26744 "10506: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 26944 "10748: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 27144 "10968: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 27344 "11189: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 27544 "11418: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 27744 "11659: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 27944 "11886: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 28144 "12106: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 28344 "12217: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 28544 "12403: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 28744 "12616: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 28944 "12785: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 29144 "13005: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 29344 "13109: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 29544 "13162: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 29744 "13363: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 29944 "13597: Clean"

{1993 Route-630 North} 1993 25 0.0 5 26539 F 30144 "13657: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 30344 "13870: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 30544 "14097: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 30744 "14158: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 30944 "14218: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 31144 "14287: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 31344 "14514: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 31544 "14713: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 31744 "14933: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 31944 "15153: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 32144 "15368: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 32344 "15596: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 32544 "15823: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 32744 "16037: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 32944 "16243: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 33144 "16472: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 33344 "16532: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 33544 "16585: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 33744 "16806: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 33944 "17033: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 34144 "17263: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 34344 "17504: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 34544 "17710: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 34744 "17835: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 34944 "18106: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 35144 "18321: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 35344 "18541: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 35544 "18645: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 35744 "18844: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 35944 "18904: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 36144 "19110: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 36344 "19311: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 36544 "19531: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 36744 "19584: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 36944 "19753: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 37144 "20026: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 37344 "20254: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 37544 "20476: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 37744 "20703: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 37944 "20930: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 38144 "21157: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 38344 "21268: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 38544 "21476: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 38744 "21689: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 38944 "21909: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 39144 "22136: Clean"

{1993 Route-630 North} 1993 25 0.0 5 26539 F 39344 "22307: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 39544 "22558: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 39744 "22757: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 39944 "22956: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 40144 "23162: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 40344 "23371: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 40544 "23598: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 40744 "23825: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 40944 "24053: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 41144 "24266: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 41344 "24517: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 41544 "24744: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 41744 "24971: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 41944 "25170: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 42144 "25378: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 42344 "25620: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 42544 "25862: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 42744 "26089: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 42944 "26331: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 43144 "26502: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 43344 "26620: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 43544 "26673: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 43744 "26791: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 43944 "26889: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 44144 "27116: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 44344 "27315: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 44544 "27544: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 44744 "27771: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 44944 "27889: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 45144 "28116: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 45344 "28343: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 45544 "28549: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 45744 "28776: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 45944 "29031: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 46144 "29258: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 46344 "29481: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 46544 "29722: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 46744 "29977: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 46944 "30204: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 47144 "30370: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 47344 "30599: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 47544 "30826: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 47744 "31009: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 47944 "31236: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 48144 "31499: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 48344 "31728: Crack"

{1993 Route-630 North} 1993 25 0.0 5 26539 F 48544 "31963: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 48744 "32176: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 48944 "32403: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 49144 "32633: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 49344 "128: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 49544 "181: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 49744 "423: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 49944 "476: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 50144 "710: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 50344 "763: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 50544 "992: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 50744 "1219: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 50944 "1272: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 51144 "1376: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 51344 "1429: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 51544 "1663: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 51744 "1892: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 51944 "2090: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 52144 "2317: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 52344 "2320: Crack"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 52544 "2735: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 52744 "2943: Clean"
{1993 Route-630 North} 1993 25 0.0 5 26539 F 52944 "3142: Clean"

Appendix B Khoros Workspace

The followings are the Khoros programming codes used for the image processing to isolate the distress features from the background. It also has a capability of indicating the absence or presence of the distresses on the image.

```
# Khoros Visual Programming Workspace
#
# cantata workspace file (/pcfs/dot_4t_d) was created
# on Sun May 18 21:36:25 1997
# by user (Hyungkee Oh)
#
WorkspaceBegin: 2.1

VariablesBegin:

#
# list of currently declared variables
#
mp = 138.003
x1 = 138
mw = 122.761
sw = 2.01592
xw = 123
m2 = 122.761
x2 = 123
n1 = 71
m1 = 134.055
s2 = 2.01592
k2 = -12.9269
k1 = -2.83841
s1 = 5.19797
prt = 1/(1+exp(-(63.52+(99.83*(1/s1))-295.16*(log10(1.4-k1))+106.59*(log10(-2.09 -
k2))+101.07*log10((s1/s2)/(k2/k1))+202.94*log10(s2)-0.605*m1+0.656*n1-
1.855*(s1/s2)+0.62*(k2/k1)-16.4*k1+6.31*((s1/s2)/(k2/k1))-40.77*s2)))
fnzero1 = 447

VariablesEnd:

#  Glyph 'User defined'
Glyph:DESIGN:user_def::localhost:1:2:142::  -o /temp/crk.tst
#  Glyph 'Extract'
Glyph:DATAMANIP:kextract::localhost:3:62:142:: -wsize '600' -hsize '90' -woff '10' -hoff
'370' -subpos 0
#  Loop 'While Loop'
LoopBegin:While Loop:while:localhost:5:163:143: -init 'width=0;fnzero=0' -test 'width <
451 && fnzero<251' -update 'width=width+150;fnzero'
VariablesBegin:
```

```
#
# list of currently declared variables
#
width=width+150;fnzero
fnzero = 447
VariablesEnd:
#  Loop 'While Loop'
LoopBegin:While Loop:while:localhost:1:622:2: -init 'xw -mw' -test 'xw - mw > 0.3' -
update 'xw - mw'
VariablesBegin:
# No variables currently declared. #
VariablesEnd:
#  Glyph 'Statistics'
Glyph:DATAMANIP:kstats::localhost:1:662:82:: -whole -mean -sd -maxval
#  Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:3:722:122:: -mapdata 0 -woff '0' -hoff '0' -doff '0' -
toff '0' -eoff '1' -var 'sw' -val
#  Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:5:722:82:: -mapdata 0 -woff '0' -hoff '0' -doff '0' -
toff '0' -eoff '0' -var 'mw' -val
#  Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:7:722:162:: -mapdata 0 -woff '0' -hoff '0' -doff '0' -
toff '0' -eoff '2' -var 'xw' -val
#  Glyph 'Clip Above'
Glyph:DATAMANIP:kclipabove::localhost:9:602:2:: -uc 'mw - (1.2 * sw)'
#  ExtPort 'External Output (1)'
ExtPort:out:External Output (1):o1:11:739:29:
#  ExtPort 'External Input (2)'
ExtPort:in:External Input (2):i1:13:505:29:
#  Connections 'Statistics'
NodeConnection:data:1:o:5:i
NodeConnection:data:1:o:3:i
NodeConnection:data:1:o:7:i
#  Connections 'Print Value'
#  Connections 'Print Value'
#  Connections 'Print Value'
#  Connections 'Clip Above'
NodeConnection:data:9:o:1:i
NodeConnection:data:9:o:11:
#  Connections 'External Output (1)'
#  Connections 'External Input (2)'
NodeConnection:data:13::9:i
AnnotationsBegin
AnnotationsEnd
LoopEnd:While Loop
#  Conditional 'Merge Paths'
```

```
Conditional:CONDITIONAL:merge::localhost:3:482:322::
# Conditional 'If Else'
Conditional:CONDITIONAL:if_else::localhost:5:242:322:: -condition 'prt < 0.5'
# Conditional 'Expression'
Conditional:CONDITIONAL:expr::localhost:7:162:322:: -expression 'prt = 1/(1+exp(-
(63.52+(99.83*(1/s1))-295.16*(log10(1.4-k1))+106.59*(log10(-2.09 -
k2))+101.07*log10((s1/s2)/(k2/k1))+202.94*log10(s2)-0.605*m1+0.656*n1-
1.855*(s1/s2)+0.62*(k2/k1)-16.4*k1+6.31*((s1/s2)/(k2/k1))-40.77*s2)))\n'
# Glyph 'Median'
Glyph:IMAGE:imedian::localhost:9:562:322:: -wsize '3' -hsize '3' -reps '1'
# Glyph 'Thresh Above'
Glyph:DATAMANIP:kthreshabove::localhost:11:402:362:: -uc '128' -fval '0' -tval '255'
# Glyph 'CLEAR'
Glyph:DATAMANIP:kbitclear::localhost:13:342:362::
# Glyph 'Thresh Above'
Glyph:DATAMANIP:kthreshabove::localhost:15:362:302:: -uc 'm2 - 5' -fval '255' -tval '0'
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:17:762:162:: -mapdata 0 -woff '0' -hoff '0' -doff '0'
-toff '0' -eoff '3' -var 'x2' -val
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:19:762:122:: -mapdata 0 -woff '0' -hoff '0' -doff '0'
-toff '0' -eoff '2' -var 'k2' -val
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:21:762:82:: -mapdata 0 -woff '0' -hoff '0' -doff '0' -
toff '0' -eoff '1' -var 's2' -val
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:23:762:42:: -mapdata 0 -woff '0' -hoff '0' -doff '0' -
toff '0' -eoff '0' -var 'm2' -val
# Glyph 'Statistics'
Glyph:DATAMANIP:kstats::localhost:25:702:2:: -whole -mean -sd -skew -maxval
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:27:562:122:: -mapdata 0 -woff '0' -hoff '0' -doff '0'
-toff '0' -eoff '2' -var 'xw' -val
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:29:562:82:: -mapdata 0 -woff '0' -hoff '0' -doff '0' -
toff '0' -eoff '1' -var 'sw' -val
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:31:562:42:: -mapdata 0 -woff '0' -hoff '0' -doff '0' -
toff '0' -eoff '0' -var 'mw' -val
# Glyph 'Statistics'
Glyph:DATAMANIP:kstats::localhost:33:502:42:: -whole -mean -sd -maxval
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:35:442:202:: -mapdata 0 -woff '0' -hoff '0' -doff '0'
-toff '0' -eoff '3' -var 'n1' -val
# Glyph 'Print Value'
```

```
Glyph:DATAMANIP:kprval::localhost:37:442:162:: -mapdata 0 -woff '0' -hoff '0' -doff '0'
-toff '0' -eoff '2' -var 'k1' -val
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:39:442:122:: -mapdata 0 -woff '0' -hoff '0' -doff '0'
-toff '0' -eoff '1' -var 's1' -val
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:41:442:82:: -mapdata 0 -woff '0' -hoff '0' -doff '0' -
toff '0' -eoff '0' -var 'm1' -val
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:43:442:242:: -mapdata 0 -woff '0' -hoff '0' -doff '0'
-toff '0' -eoff '4' -var 'x1' -val
# Glyph 'Statistics'
Glyph:DATAMANIP:kstats::localhost:45:382:82:: -whole -mean -sd -skew -minval -
maxval
# Glyph 'Clip Above'
Glyph:DATAMANIP:kclipabove::localhost:47:362:2:: -uc 'mp'
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:49:302:62:: -mapdata 0 -woff '0' -hoff '0' -doff '0' -
toff '0' -eoff '0' -var 'mp' -val
# Glyph 'Statistics'
Glyph:DATAMANIP:kstats::localhost:51:242:62:: -whole -mean
# Glyph 'Map Data'
Glyph:DATAMANIP:kmapdata::localhost:53:262:2::
# Glyph 'Set Attribute'
Glyph:DATAMANIP:ksetdattr::localhost:55:202:2:: -maskpres 0 -cspace 1
# Glyph 'Extract'
Glyph:DATAMANIP:kextract::localhost:57:142:2:: -wsize '150' -hsize '90' -woff 'width' -
hoff '0' -subpos 0
# ExtPort 'External Output (1)'
ExtPort:out:External Output (1):o1:59:699:349:
# ExtPort 'External Input (2)'
ExtPort:in:External Input (2):i1:61:45:29:
# Glyph 'Display Image'
Glyph:ENVISION:putimage::localhost:63:143:103:: -xoffset '0' -yoffset '0' -complex 5 -
normaltype 1 -normalmethod 1 -redcol 1 -greencol 2 -bluecol 3 -redfn 'M0' -greenfn 'M1' -
bluefn 'M2'
# Glyph 'Display Image'
Glyph:ENVISION:putimage::localhost:65:762:262:: -xoffset '0' -yoffset '0' -complex 5 -
normaltype 1 -normalmethod 1 -redcol 1 -greencol 2 -bluecol 3 -redfn 'M0' -greenfn 'M1' -
bluefn 'M2'
# Glyph 'Statistics'
Glyph:DATAMANIP:kstats::localhost:67:602:242:: -whole -zpts
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:69:682:242:: -mapdata 0 -woff '0' -hoff '0' -doff '0'
-toff '0' -eoff '0' -var 'fnzero' -val
# Connections 'While Loop'
```

NodeConnection:data:1:o1:25:i
NodeConnection:data:1:o1:7:i
Connections 'Merge Paths'
NodeConnection:data:3:o:9:i
Connections 'If Else'
NodeConnection:data:5:o1:15:i
NodeConnection:data:5:o2:13:i
Connections 'Expression'
NodeConnection:data:7:o:5:i
Connections 'Median'
NodeConnection:data:9:o:59:
NodeConnection:data:9:o:65:i
NodeConnection:data:9:o:67:i
Connections 'Thresh Above'
NodeConnection:data:11:o:3:i2
Connections 'CLEAR'
NodeConnection:data:13:o:11:i
Connections 'Thresh Above'
NodeConnection:data:15:o:3:i1
Connections 'Print Value'
NodeConnection:control:17:out:7:in
Connections 'Print Value'
Connections 'Print Value'
Connections 'Print Value'
Connections 'Statistics'
NodeConnection:data:25:o:23:i
NodeConnection:data:25:o:21:i
NodeConnection:data:25:o:19:i
NodeConnection:data:25:o:17:i
Connections 'Print Value'
NodeConnection:control:27:out:1:in
Connections 'Print Value'
Connections 'Print Value'
Connections 'Statistics'
NodeConnection:data:33:o:31:i
NodeConnection:data:33:o:29:i
NodeConnection:data:33:o:27:i
Connections 'Print Value'
Connections 'Print Value'
Connections 'Print Value'
Connections 'Print Value'
Connections 'Print Value'
Connections 'Statistics'
NodeConnection:data:45:o:41:i
NodeConnection:data:45:o:39:i
NodeConnection:data:45:o:37:i

```
NodeConnection:data:45:o:35:i
NodeConnection:data:45:o:43:i
# Connections 'Clip Above'
NodeConnection:data:47:o:45:i
NodeConnection:data:47:o:33:i
NodeConnection:data:47:o:1:i1
# Connections 'Print Value'
NodeConnection:control:49:out:47:in
# Connections 'Statistics'
NodeConnection:data:51:o:49:i
# Connections 'Map Data'
NodeConnection:data:53:o:47:i
NodeConnection:data:53:o:51:i
# Connections 'Set Attribute'
NodeConnection:data:55:o:53:i
# Connections 'Extract'
NodeConnection:data:57:o:55:i
NodeConnection:data:57:o:63:i
# Connections 'External Output (1)'
# Connections 'External Input (2)'
NodeConnection:data:61::57:i
# Connections 'Display Image'
# Connections 'Display Image'
# Connections 'Statistics'
NodeConnection:data:67:o:69:i
# Connections 'Print Value'
AnnotationsBegin
AnnotationsEnd
LoopEnd:While Loop
# Conditional 'If Else'
Conditional:CONDITIONAL:if_else::localhost:7:362:142:: -condition 'fnzero1 < 251'
# Glyph 'a_prtcln'
Glyph:ENCAP:buprtcrk1::localhost:9:462:102::
# Glyph 'Display Image'
Glyph:ENVISION:putimage::localhost:11:163:43:: -xoffset '0' -yoffset '0' -complex 5 -
normaltype 1 -normalmethod 1 -redcol 1 -greencol 2 -bluecol 3 -redfn 'M0' -greenfn 'M1' -
bluefn 'M2'
# Glyph 'a_prtcrk'
Glyph:ENCAP:buprtcrk::localhost:13:462:202::
# Glyph 'Statistics'
Glyph:DATAMANIP:kstats::localhost:15:262:62:: -whole -zpts
# Glyph 'Print Value'
Glyph:DATAMANIP:kprval::localhost:17:322:62:: -mapdata 0 -woff '0' -hoff '0' -doff '0' -
toff '0' -eoff '0' -var 'fnzero1' -val
# Glyph 'User defined'
```

```
Glyph:DESIGN:user_def::localhost:29:323:283::  -o
/usr/local/MuTech/pbmplus/bin/image.rast
#  Glyph 'Edit Image'
Glyph:ENVISION:editimage::localhost:31:462:282:: -priv 0 -alloc 1 -x '-1' -y '-1' -update
'1'
#  Connections 'User defined'
NodeConnection:data:1:o:3:i
#  Connections 'Extract'
NodeConnection:data:3:o:5:i1
NodeConnection:data:3:o:11:i
#  Connections 'While Loop'
NodeConnection:data:5:o1:7:i
NodeConnection:data:5:o1:15:i
#  Connections 'If Else'
NodeConnection:data:7:o1:9:i
NodeConnection:data:7:o2:13:i
#  Connections 'a_prtcln'
#  Connections 'Display Image'
#  Connections 'a_prtcrk'
#  Connections 'Statistics'
NodeConnection:data:15:o:17:i
#  Connections 'Print Value'
NodeConnection:control:17:out:7:in
#  Connections 'User defined'
NodeConnection:data:29:o:31:i
#  Connections 'Edit Image'
AnnotationsBegin
AnnotationsEnd
WorkspaceEnd: 2.1
```

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