AUTOMATED PAVEMENT CONDITION ANALYSIS BASED ON AASHTO GUIDELINES

by

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Abstract

In this thesis, we present an automated system for detection and classification of cracks, based on the new standard proposed by 'American Association of State Highway and Transportation Officials (AASHTO)'. The AASHTO standard is a draft standard, that attempts to overcome the limitations of current crack quantifying and classification methods. In the current standard, the crack classification relies heavily on the judgment of the expert. Thus the results are susceptible to human error. The effect of human error is especially severe when the amount of data collected is large. This lead to inconsistencies even if a single standard is being followed. The new AASHTO guidelines attempt to develop a method for consistent measurement of pavement condition.

Gray scale images of the road are captured by an image capture vehicle and stored on a database. Through steps of thresholding, line detect and scanning, the gray scale image is converted to binary image, with 'zeros' representing cracked pixels. PCA analysis, followed by closing and filtering operation, are carried out on the gray scale image to identify cracked sub-images. The output from the filtering operation, is then replaced with its binary counterpart.

In the final step the crack parameters are calculated. The region around the crack is divided into blocks of 32×32 to aproximate and calculate the crack parameters with ease. The width of the crack is approximated by the average width of crack in each block. The orientation of the crack is calculated from the angle between direction of travel and the line joining the ends of the crack. Length of the crack is the displacement between the ends of the crack, and the position of the crack is calculated from the midpoint of the line joining the end points.

Table of Contents

List of Figures

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Chapter 1

Introduction

This chapter, introduces the background, motivation, proposed approach and the organization of this thesis work.

1.1 Background

Pavement distresses are anomalous phenomena that may occur on road surfaces. Pavement cracking is the one of the most common and extensive phenomena. Road cracking affects the quality of ride to a great extent and hence attracts significant attention from the departments. To ensure timely treatment, the authorities try to analyze the condition of the roads yearly. Road analysis is done along all the highways around the country. The roads are classified based on the county and route, and each one is divided into sections depending on the mile markers. Different types of cracks can occur on the road, and each type has different impact on the ride quality and can be an indication of excessive load or structural damage on the road. To deduce useful information on the road quality, reporting is done on severity and type of crackings on each section of the road.

In the current system, the road surface is imaged using an imaging vehicle. The vehicle houses cameras, computers, GPS and pavement lighting system. The vehicle captures the image of the road every $8m$, at highway speed. The captured images are displayed on the computer system. Whenever the computer operator notices a crack on the image, the vehicle is stopped for further analysis of that crack. Any distress which runs all along the road and which at least has the width of a quarter dollar coin is chosen as a crack for analysis. The classification of the crack is left to the discretion of an expert and is done visually by the expert depending on whether the crack has been sealed, orientation of the crack and the roughness of the crack. The observations made by the expert are logged onto the computer. The logging is based on the county, route and the mile marker at which the observations are made. Reporting is done for each section of road, on the severity of cracks and number of cracks in that section.

1.2 Motivation

In the current methods, the crack classification relies heavily on the judgment of the expert. Thus the results are susceptible to human error. This effect of human error is especially severe when the amount of data collected is large. Also, since the classification is left to discretion of an individual, the same section of road, maybe classified differently by another individual. This lead to inconsistencies, even if a single standard is being followed. Since the current system being followed is partially manual, the operator has to stop the vehicle at each crack, and because of the frequent stops, the imaging vehicle may have to be run at a speed lesser than the highway speed. The lower speed and the frequent stops may pose serious accident-risk to the operator and driver of the vehicle.

Lot of work has been going on in past for crack detection and analysis, but none of these accounts to a standardized automated system. Manual detection of cracks on the pavements is discussed in [5]. Once cracked regions are photographed, the images are processed using a software to segment the cracked region. This is method is not only cumbersome on long highways but also is susceptible to human errors. [6] introduces the idea of using histogram technique to automaticaly detect cracks, but the shortcoming of this method is that it fails to detect multiple cracks on the pavement. Neural network techiques for crack detection and classification are discussed in [7] and [9], but the amount of data tested in these methods are not large enough to give a conclusive evaluation of the technique.

The American Association of State Highway and Transportation Officials(AASHTO), is trying to standardize the tools and procedures used to quantify the cracking distress on the roads, so as to make the technique more consistent and less susceptible to human errors [1]. The standard covers the procedures for quantifying cracking distress in asphalt pavement surfaces utilizing automated methods. Detailed specifications are not given for the measuring equipment or instruments. Any equipment which meets the functionality of the standard is considered acceptable. The thesis presented here proposes an automated crack quantifying system for the Kansas Department of Transport, based on the AASHTO guidelines.

1.3 Proposed Approach

The thesis proposes an automated crack analysis system based on the AASHTO guidelines [1]. The system tries to overcome the limitations faced by the current methods and standardize the crack detection and classification methods. Since the system is fully automated, it will require no human interaction to detect and analyze the cracks on the road surface. A standardized automated system will help reduce the inconsistencies and errors that may occur during the analysis and classification.

The first stage of the system is the data collection. The data collected are the images of the road. For undivided highways, the images are collected only in one direction, and for divided highways the images are collected from the outside lane. The survey is done in the same direction and same lane, for each survey cycle. Images of the road are captured by an image capture vehicle built by 'International Cybernetics Corporation Digital Image Data Collection System'[10]. The images of size 3344×2048, are captured for every 8meters of the highway at 60mph. The image resolution reaches 1.93mm for every pixel. The images are classifed based on the county and route to which it belongs, and then stored onto a hard disk, which constitutes our database.

The images are extracted one by one from the database for analysis. As per the AASHTO guidelines, the region between the lane separation and shoulder stripes is identified. Only those cracks which fall within this region are analyzed and classified. Once the region of interest is found out, the position of the outer and inner wheel paths are calculated as per the AASHTO guidelines. The region is then divided into five different zones based on the dimensions provided by the AASHTO. The zones will help identify the wheelpaths on road. The cracks on the wheelpaths affects the ride quality and hence are considered more problematic than the rest.

The image obtained after removing the unwanted region is processed to classify the pixels into cracked and uncracked. To reduce the computational time and to increase the chance of detecting the cracked pixels, the image is resized to 25% its original size. The pixels in the resized image are then classified into cracked and uncracked, using the 'thresholding' technique. The pixels which have values lower than the local threshold are classified as cracked and the rest as uncracked. To improve the accuracy of pixel level classification, a 'line detect' followed by a 'scanning' technique is used. Thus the gray scale image is converted to binary with 'zeros' representing cracked pixel and 'ones' representing uncracked. After this the binary image is resized to the size of the original gray scale image.

The gray scale image is considered to be made of sub-image blocks of size 32×32 pixels. The sub-images are classified into cracked and uncracked depending on the number of cracked pixles within it. To further improve the accuracy of classification, PCA analysis is carried out on the cracked sub-images, to find the occurrence of a crack. Closing and filtering operation, is then carried out on the image to establish connectivity between the cracked sub-images, and to identify the crack(s). In the final step of identifying the cracks, the output from the filtering operation, is replaced with its binary counterpart (output from the scanning operation).

Final stage of the proposed method is crack features calculation. The region around the crack is divided into blocks of 32×32 pixels to approximate and calculate the crack parameters with ease. The width of the crack is approximated from the average width of crack in each block. The end points of the crack are found, and the orientation of the crack is calculated from the angle between direction of travel and the line joining the ends of the crack. Length of the crack is the displacement between the ends of the crack, and the position of the crack is calculated from the midpoint of the line joining the end points. The feauters thus calculated can be used to form an effective report on the condition of road.

In summary, the key contribution of this thesis is a complete suite of image processing tool that is effective in detecting pavement cracks and calculating crack features. This is the first effort in developing an automated pavement crack analysis sytem that conforms to the emerging AASHTO standard.

1.4 Organization of Thesis

The rest of the thesis is organized as follows: Chapter 2 will detail the current methods being used for crack quantification and the guidelines put forward by AASHTO. Chapter 3 introduces the proposed method, and explains the steps in proposed method with a flow chart. The preprocessing and pixel level crack detection stages are discussed in chapter 4. Chapter 5 will explain how the image is classified into cracked and uncracked, and how each of the crack features are calculated. A Windows application implemented for detection and classification of the cracks, is discussed in chapter 6. Chapter 7 will detail the reporting mechanism of the application. The future research direction and conclusion are provided in chapter 8.

Chapter 2

AASHTO standard

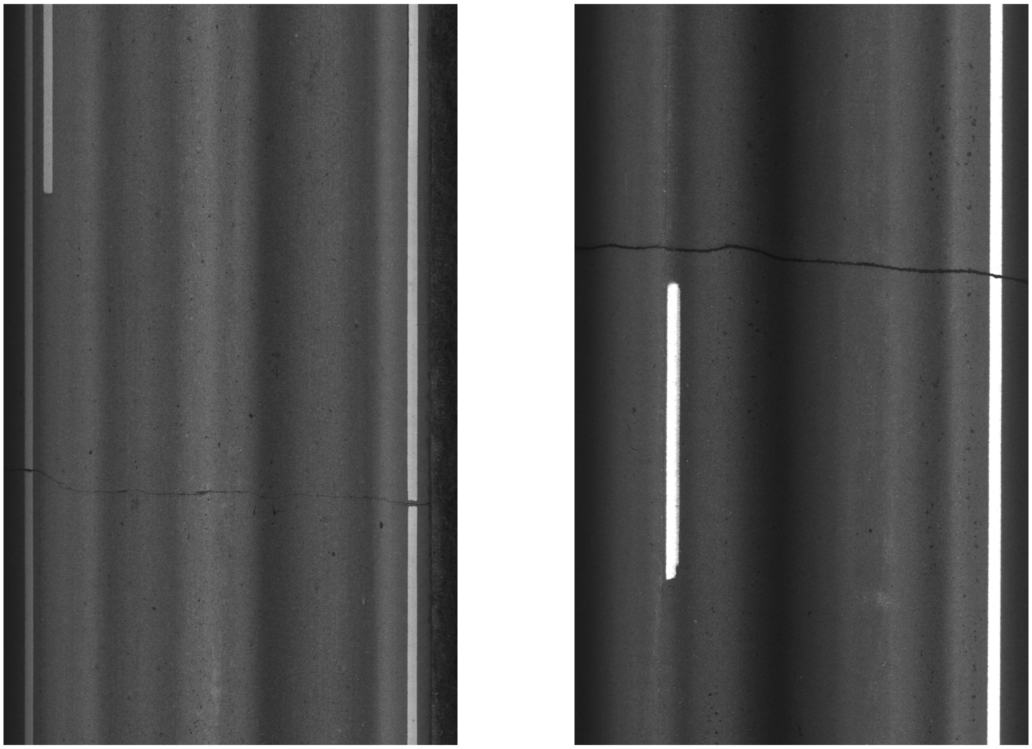
This chapter, introduces the types of pavement distresses, and how they are being quantified and classified under the existing pavement distress analysis standards. Section 2.2 looks at the steps and methods followed by the existing standard for distress analysis. It also talks about the need for an automated crack detection and classification method. Section 2.3 discuss the new standard proposed by American Association of State Highway and Transportation Officials. The AASHTO standard tries to overcome the limitations of current crack quantifying and classification methods. It attempts to develop a consistent method for the measurement of pavement condition.

2.1 Pavement Distress

The cracks on the road are of different types and are classified according to their orientation and structure[8]. This section talks about different types of cracks that occur on the pavement surface.

2.1.1 Transverse Cracking

Transverse cracks are the cracks which run across the width of the road, i.e. perpendicular to the direction of travel. Depending on whether they are sealed or not they can be sub classified as sealed and unsealed. A sealed crack is one which has sealant applied to it to control its growth; hence the classification is into ones which need immediate attention



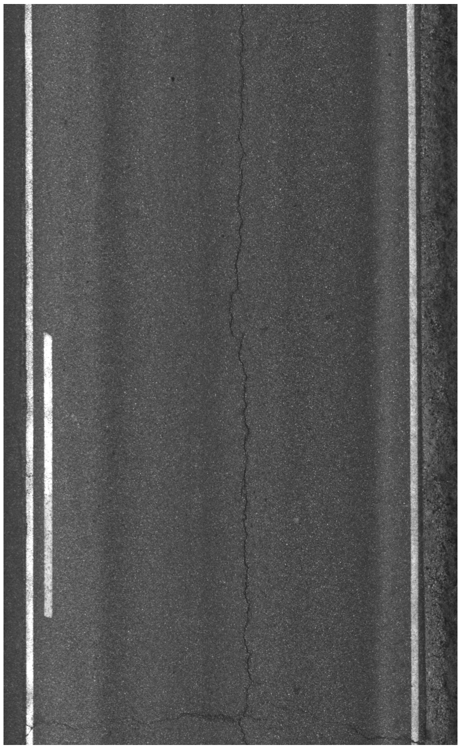
(a) Unsealed Crack (b) Sealed Crack

Figure 2.1: *Transverse Cracks*

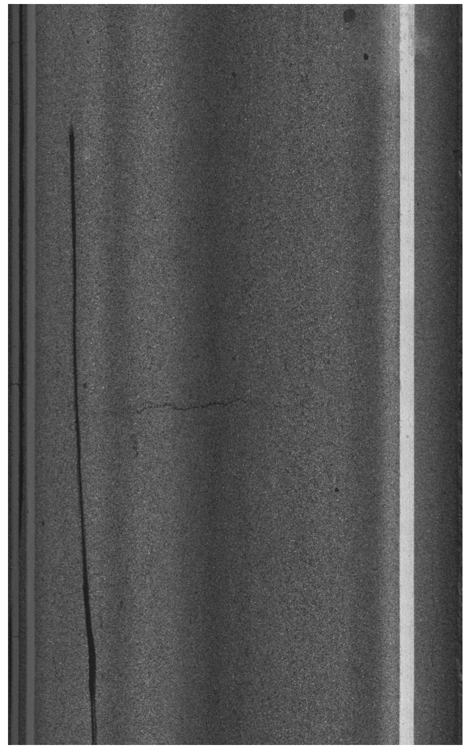
(unsealed) and ones which have been treated (sealed). Figure 2.1 shows examples of sealed and unsealed cracks . The classification of the transverse crack may also be done depending on the roughness of the crack [11]. The roughness measurement, quantified based on the International Roughness Index (IRI), gives a measure of how comfortable the ride is over the cracked surface. IRI indicates the deviation from the planar surface; hence, lower the IRI lower the severity and lesser it affects the ride quality. Based on the IRI the cracks can be classified as Code0, Code1, Code2 and Code3 cracks.

2.1.2 Longitudinal Cracking

Longitudinal cracks are the cracks which run along the length of the road, that is, parallel to the direction of travel. Similar to the transverse cracks, longitudinal cracks too can be classified as sealed and unsealed depending on whether they have been treated with sealant



(a) Unsealed Crack



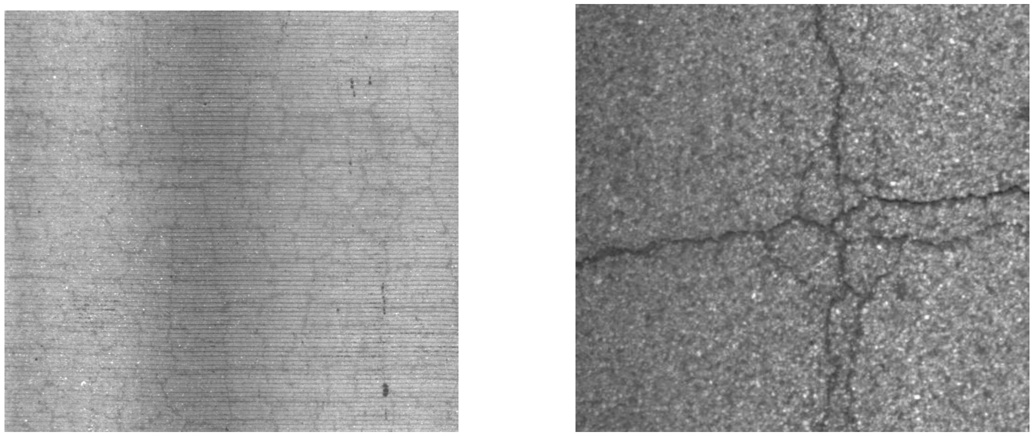
(b) Sealed Crack

Figure 2.2: *Longitudinal Cracks*

or not . Longitudinal cracks that lies on the wheel path, that is, where the wheels of a vehicle travels predominantly, can be considered more serious since it affects the ride quality more. Examples of longitudinal cracks are given in Fig 2.2.

2.1.3 Pattern Cracking

Patterns cracks are a cluster of cracks, usually with more than one cracks branching out into different cracks many times. This forms a crisscross pattern involving both transverse and longitudinal cracks. This type of crack can occur due to excessive load or structural damage beneath the surface of the road. Apart from the fact that this reduces the quality of the ride, pattern cracks can be an indication of structural damages of the road . Block cracks and fatigue cracks are examples of pattern cracks. Block cracks appear as rectangular blocks of interconnected transverse and longitudinal cracks, while the fatigue cracks are very



(a) (b)

Figure 2.3: *Pattern Cracks*

finely developed pattern that appear as secondray cracking originating from the transverse or longitudinal cracks. Figure 2.3 and Figure 2.4 show examples of pattern cracks.

2.2 Current standard for crack classification

This section looks at the current methods that are being used by the Kansas Department of Transport (KDOT) for image capture and crack classification. These images and other data collected forms the input for automated algorithm being presented in this thesis. The section also discuss the limitations of the current methods.

2.2.1 Data Collection

The data collection is done by an International Cybernetics Corporation imaging vehicle which runs along the highway at constant speed [10]. The vehicle is mounted with a front camera, a back camera, laser sensor, GPS, rack computers and pavement lighting system. The front and back mounted cameras capture the image of the road in a progressively scanned image format. The pavement lighting system ensures that the images are captured under even and efficient lighting conditions. The laser scanners mounted at the front bumper of the vehicle scans the road to generate the height profile data. The Global Positioning

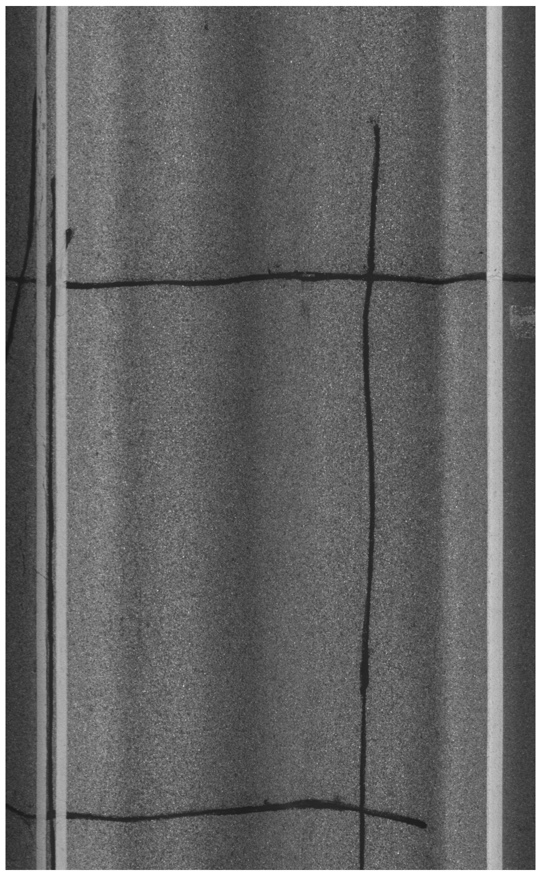


Figure 2.4: *Pattern Crack*

System gives the latitude and longitude of the point at which the data is collected. A vehicle running at 70 mph can generate efficient image and other data. Only the right lane of the road is analyzed by the vehicle and the date being collected by the vehicle is stored onto a removable hard disk. Section 3.1 talks more about the vehicle specs and data collection.

2.2.2 Crack Classification

The classification of the crack is left to the discretion of an expert. Whenever the operator of the computers encounters an image with a pavement distress, the vehicle is stopped for further analysis of the crack. Any distress which runs all along the road and which at least has the width of a quarter dollar coin is chosen as a crack for analysis. The classification is done visually by the expert depending on whether the crack has been sealed, orientation of the crack and the roughness of the crack [4]. The observations made by the expert are logged onto the computer. The logging is based on the county, route and the mile marker at which the observations are made. For reporting the route belonging to a specific county is divided into section and the report shows the types (Code) of cracks present within that section .

2.2.3 Limitations of the Current Standard

In the current standard, the crack classification relies heavily on the judgment of the expert. Thus the results are susceptible to human error. This effect of human error is especially severe when the amount of data collected is large. Also, since the classification is left to discretion of an individual, the same section of road, maybe classified differently by another individual. This lead to inconsistencies, even if a single standard is being followed. Since the current system being followed is partially manual, the operator has to stop the vehicle at each crack. The imaging vehicle has to be run at a speed very much lesser than the highway speed because of the frequent stops. The lower speed and the frequent stops may also pose serious accident-risk to the operator and driver of the vehicle.

2.3 Proposed AASHTO Standard

This section talks about the proposed AASHTO standard and how it can overcome the limitations faced by the current methods. The standard is still in its draft stage and may undergo changes in the future [1] .

2.3.1 Scope of the Standard

1. The standard covers the procedures for quantifying cracking distress in asphalt pavement surfaces utilizing automated methods. Detailed specifications are not given for the measuring equipment or instruments. Any equipment which meets the functionality of the standard is considered acceptable.

2. The data is to be collected by an imaging vehicle which travels at the prevailing highway speed.

3. For a section of a road 100 percent sample is recommended, so that the data size level is large enough to provide the confidence level required by the agency. Sample spacing will depend on the construction practices and other factors which impact the pavement continuity.

2.3.2 Definitions Within the Standard

1. Crack : A fissure of the pavement with a minimum dimension of $3cm \times .1mm$. Maximum length of the crack is $367cm$.

2. Crack Width : The average width of the crack, when measured at different points which are $3mm$ apart.

3. Crack Terminus : The point at which the width of the crack goes below and stays less than $1mm$, or the point at which it cuts another crack at more than $23degrees$, or when the maximum of $367cm$ is reached.

4. Crack Orientation : The angle between the direction of travel and the line joining the ends of the crack.

5. Crack Length : The displacement between the two ends of the crack, with a maximum length $367cm$ and whatever is beyond this length is considered as a separate crack.

6. Crack Position : The coordinates of the midpoint of the line joining the crack terminuses calculated from the shoulder of the road and the starting point of the collection point.

7. Inside Wheel Path : A longitudinal stripe of the road $750cm$ wide and centered at $875cm$ from the centre line of the lane towards the adjacent lane.

8. Outside Wheel Path : A longitudinal stripe of the road $750cm$ wide and centered at $875cm$ from the centre line of the lane towards the shoulder.

9. Measurement Zone : One of the five longitudinal stripes created by the inside and outside wheel path, and the area between them.

10. Transverse Crack : A crack at least $500cm$ long and within crack orientation between 80 and $100degrees$.

11. Longitudinal Crack : A crack at least $500cm$ long and within crack orientation between -80 and $-100degrees$.

12. Pattern Crack : A crack that is part of a network of cracks that form an identifiable grouping of shapes. For practice this includes all the cracks that are not transverse or longitudinal.

13. Summary Section : A section of the road which is length $.1km$ over which the data is summarized.

2.3.3 Data Collection

According to the standard only those cracks which fall between the stripes of the lane are considered for analysis. Anything that falls beyond this is discarded. For undivided highways the data is to be collected from only in one direction and for divided highways only from the outside lane. The standard recommends that the same direction of travel and same lane be used for every survey of the routes. The images should have resolution of 1mm and should be able to delineate 95% of .2 cm cracks and 98% of .4cm cracks. The above mentioned are the minimums specified by the standard. The rest are left to discretion of the agency using this standard depending on their requirement and engineering principles.

2.3.4 Data Reduction

The condition of pavement will have to be summarized for each summary section. The summary has to include the extent and severity of cracking within that summary section. For the longitudinal cracks the extent of cracking is given as the length of all the longitudinal cracks within the summary section. The severity of longitudinal cracking is the average width of all the longitudinal cracks. For the transverse cracks the extent of cracking is given as the length of all the longitudinal cracks within the summary section. It can also be given as the total number of transverse cracks. The severity of transverse cracking is the average width of all the transverse cracks The standard requires that the pattern crack be separated into five zones across the pavement. The zones are

1. Zone 1: Area between the inside wheel path and the lane edge of the adjacent lane

2. Zone 2: Area in the inside wheel path

3. Zone 3: Area between the wheel paths

4. Zone 4: Area in the outside wheel path

5. Zone 5: Area between the outside wheel path and the lane edge at the shoulder.

The sum of lengths of all the patterns cracks in the summary section will give the extent of pattern cracking for that zone within the section. The average width of all the pattern cracks will give the severity of pattern cracking for that zone within the section.

2.3.5 Data Reporintg and Interpretation

The calculated extent and severity for a category (transverse, longitudinal, zones) will be reported as the extent and severity for that corresponding category. The calculated values may be normalized into values between 0 and 10, with 10 being the worst. Those with the value equal to or exceeding the average of the worst 10% of the data available so far, can be regarded as 10. The rest can be normalized based on this. The agency doing the operation is free to interpret the data as best fit to its needs. The increase in the extent of cracking in the zones 2 and 4 than that in zone 3 may be interpreted as impact of traffic loading. The standard tires to lay the foundation for an image analysis method which can reduce the human error. Since the all the aspects of a crack and reporting is covered by the standard inconsistencies which can occur due to human judgment is greatly reduced. Also, it is very easy devise an automated scheme based on the guidelines given by the standard.

2.4 Summary

This chapter, introduced the types of cracks that can be expected on a pavement giving example image(s) for each type of crack. The chapter presented the current pavement analysis standards, along with their limitations. The chapter also introduced the new proposed AASHTO standard. The scope, definitions, data collection and reporting as given by the standard is discussed. The next chapter, outlines a measurement system, which uses AASHTO guidelines to devise an automated system for detection and estimation of cracks.

Chapter 3

Proposed Measurement System

This chapter, discusses the proposed measurement system which uses the AASHTO standard as the guideline to devise an automated system for detection and classification of cracks, and reporting.

3.1 Flow chart of the system

Figure 3.1 illustrates the steps involved in the proposed automated crack detection and analysis system. The first step in the process is image data collection. This is discussed in detail in section 3.3. The collected images are then classified based on route and county, and are stored to a removable hard disk. These images constitute our database. The images are extracted one by one from the database for analysis. The image is first taken through a preprocessing stage which is used to enhance the image quality and increase the probability of crack detection. The next stage involves the detection the cracked pixels and eventual identification of cracked regions. Once the location of the crack is known, the crack features (width, length and orientation) are calculated. These are discussed in detail in chapter 4. Based on the severity and extent of the crack the report is generated for each summary section. This is further discussed in section 3.5.

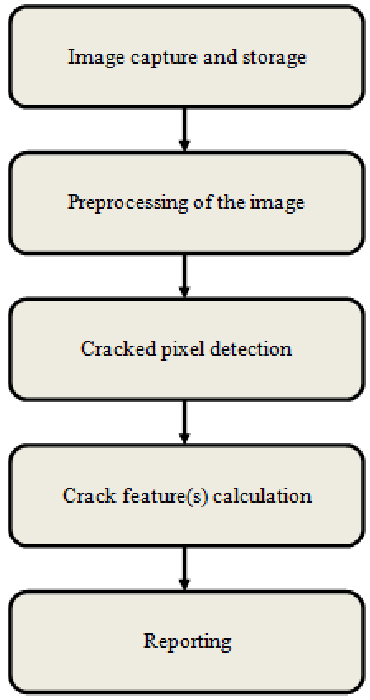


Figure 3.1: *Steps in the proposed system*

3.2 Measurement vehicle spec

This section talks about the measurement vehicle driven along the highway to capture the image of the pavement. It discusses the instruments and methods used by the vehicle for data collection. The vehicle used here is the one built by International Cybernetics Corporation Digital Image Data Collection System [10]. It provides the hardware and software required to collect high quality digital images of the pavement at highway speeds. The data collection system consists camera sub system which is mounted outside the vehicle and a image capture subsystem which installed inside the vehicle. Also provided are the pavement lighting system, laser sensors and the GPS .

The camera subsystem utilizes a front facing and pavement facing digital cameras mounted on sealed enclosure. The cameras have pan and tilt options which can be controlled from inside the vehicle. The minimum camera is a DVC 1310C digital progressive scan color camera with a resolution of 1300x1024. The cameras being used for our purpose captures images at size 3344x2048, with pixel resolution approaching 1.93mm. The camera captures the image at the rate of one image for every 8meters at 60mph. The subsystem is built to with stand shock, vibrations and other elements affecting the vehicle while travelling at 75mph. The image capture subsystem consists of a rugged computer which can withstand the extreme conditions that may arise within the vehicle while travelling at 75 mph. The unit uses Pentium IV 1.7 GHz processors with 512MB RAM, with an Windows 2000 operating system. The subsystem contains 80 GB hard disk for the windows operating system with two additional 80GB removable hard disk for data storage. The images are captured on high speed 24-bit color PCI imaging PCB and displayed on 15 panel display. The images are stored in the hard disk in JPEG format. The lighting system consists of ten 150 Watts lamps. This ensures an even and efficient lighting condition for image capture. The laser sensors fitted at the front bumper can generate the profile data .

The efficiency of the image capture is system is very important as the success of the algorithm depends very much on the quality of the images being captured. Artifacts introduced into the images may reduce the algorithm's ability to identify the cracks correctly. Therefore better the image better will be the results.

3.3 Crack Feature Calculation

The crack features, that need to be calculated are its width, length, orientation and position. These are detailed in section 2.3.2. The first step in feature calculation is pre-processing of the image. This helps in enhancing the image and increases the probability of detection of the cracked pixels. The next step is detection of the cracked pixels and identification of the cracked regions. Once the cracked regions are identified, each region is checked for presence of more than one crack. Each crack is then analysed individualy, to calculate its features.

3.4 Reporting

Reporting is the way an end user can make any useful interpretations out of the images that were analyzed. The report generation is based on the extent and severity of cracking. The AASHTO standard has laid down the guidelines to generate a report[1]. A report is generated for each summary section. The length of the summary section is $.1km$, so the report will contain the crack details of 15 contiguous images, since image represent a road section of $6.45m$. The report generated will include separate sections for the transverse, longitudinal and pattern cracks. Reporting is based on the extent and severity of each category of cracks. The extent of the longitudinal crack is given as the sum of lengths of all the longitudinal cracks in the summary section. The severity of the crack is the average width of the calculated width of all the longitudinal cracks within the section. The extent of the transverse cracking is reported as the total number of transverse cracks in the summary section and the severity is reported as the average width of the same. The pattern cracks will have separate reporting for the five different zones for each summary section. The extent of pattern cracking in a zone is reported as the total length of the pattern cracks for that zone within the summary section. The severity of pattern cracking in a zone is reported as the average width of the pattern cracks for that zone within the summary section. The use and interpretation of this report is left to the discretion of the end user, depending on the requirement.

3.5 Summary

In this chapter we presented an overview of the proposed system for pavement analysis that takes into consideration the guidelines of the AASHTO standard. The flow chart of the system is explained, wherein the image is captured, preprocessed, cracks are detected, features are calculated and a report is generated. The specs of the image capture vehicle have been detailed, giving its subsystems and their features. Also discussed is the reporting for each category of cracks. Next chapter provides the details about the preprocessing and crack detection steps.

Chapter 4

Preprocessing and Detection

In this chapter, we detail the pre processing of image, and detection of the cracked pixels. The images we are dealing with are of size 3344×2048 pixels, with a pixel resolution of $1.93 \times 1.93mm$. The preprocessing of the digital image helps in increasing the chance of a pixel being correctly classified as cracked or uncracked. At the detection stage, the pixels that represent the crack are classified as the cracked pixel and the rest are classified as uncracked. This helps in locating the position of cracks and calculating its features.

4.1 Finding the Region of interest

This is the first step in the preprocessing stage. Region of interest is the area of the road between the shoulder stripe and the lane separation stripe . Only the cracks that fall within the region of interest needs to be analyzed. The stripes are painted with bright colors and occur with high pixel value (> 175) in the gray scale image. The stripes are usually of width 3 to 4 inches. These two properties make it easier to search for the stripe within the image. The image is sampled at ten different places (rows) along the length for the stripe. For each sampled row the pixels from 1 to 700 are analyzed for lane separation stripes and pixels from 2600 to 3344 is analyzed for shoulder separation. At each pixel position a set of 60 neighboring pixels are taken. This will correspond to the maximum stripe width. Within these set of pixels difference with the immediate neighbor is calculated. A difference greater than 55 indicates a possible edge of pixel. Once a change is detected, the pixels on either side of it is checked once again for difference greater than 55. If the second difference is detected and it falls between 32 and 60 pixel distance from the first detected difference, a stripe is reported. The edge which faces into the image is taken at the point at which the region of interest starts or ends. Figure 4.2 shows the original image and the image after cutting out the region of interest.Pseudo code for finding the shoulder stripe is given below.

```
% Sample at 10 rows
for i = 1:205:2048
    % Search for shoulder lane
    for j = 2600:3344
        % Check for stripe edge
        if abs(image(i,j)-image(i,j+1))>55
            % Check for another stripe edge\end{footnotesize}
            for k = j-60:j+60
                % If another edge is found then break\end{footnotesize}
                if abs(image(i,k)-image(i,k+1))>55 && 32<abs(k-j)>60
                    %A crack is detected;
                    %Break from all the loops;
                end
            end
        end
    end
end
```

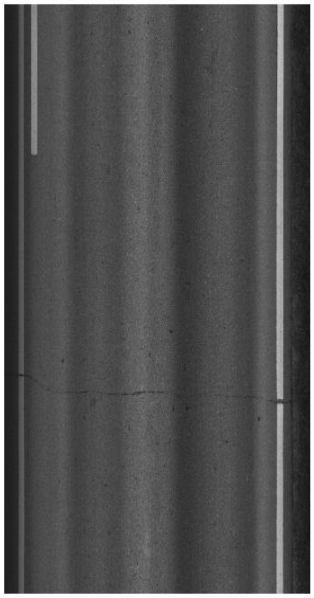
Figure 4.1: *Pseudo code for finding stripes*

Once the region of interest is found out the position of the outer and inner wheel paths are calculated. The wheel paths are given as

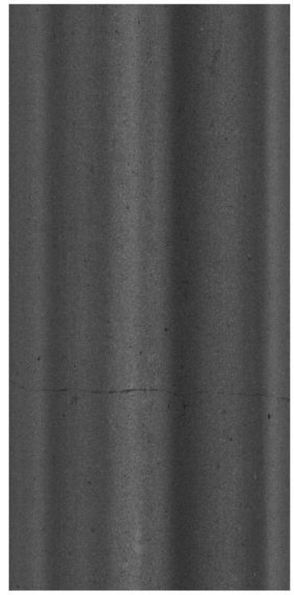
1. Inside Wheel Path: A longitudinal stripe of the road 750 cm wide and centered at 875 cm from the centre line of the lane towards the adjacent lane.

2. Outside Wheel Path: A longitudinal stripe of the road 750 cm wide and centered at 875 cm from the centre line of the lane towards the shoulder.

Once the wheel paths are known the region of interest can be divided into five different zones as given in section 2.3.4. Figure 4.3 shows the image with the zones marked.



(a) Original Image



(b) Only region of interest

Figure 4.2: *Region of interest*

4.2 Cracked Pixel Detection

This section discuss the steps involved in identifying the pixels which are part of the crack.

4.2.1 Image Resizing and Thresholding

The image obtained after removing the unwanted region is resized to 25% its original size using bicubic extrapolation technique [12]. This reduces the computational time in the next few steps, since the number of pixels to be processed has been greatly reduced. Apart from this, resizing the image has been found to increase the chance of detecting the cracks.

With the bicubic technique the image can be resized with least quality degradation. Bicubic technique is an extension of of the cubic technique for interpolation in 2D grid. Bicubic interpolation uses bicubic calculation, to interpolate a data at a point, using the information from sixteen surrounding pixels. The results of bicubic interpolation are smooth and with lower interpolation artifacts. Examples of transverse and longitudinal cracked

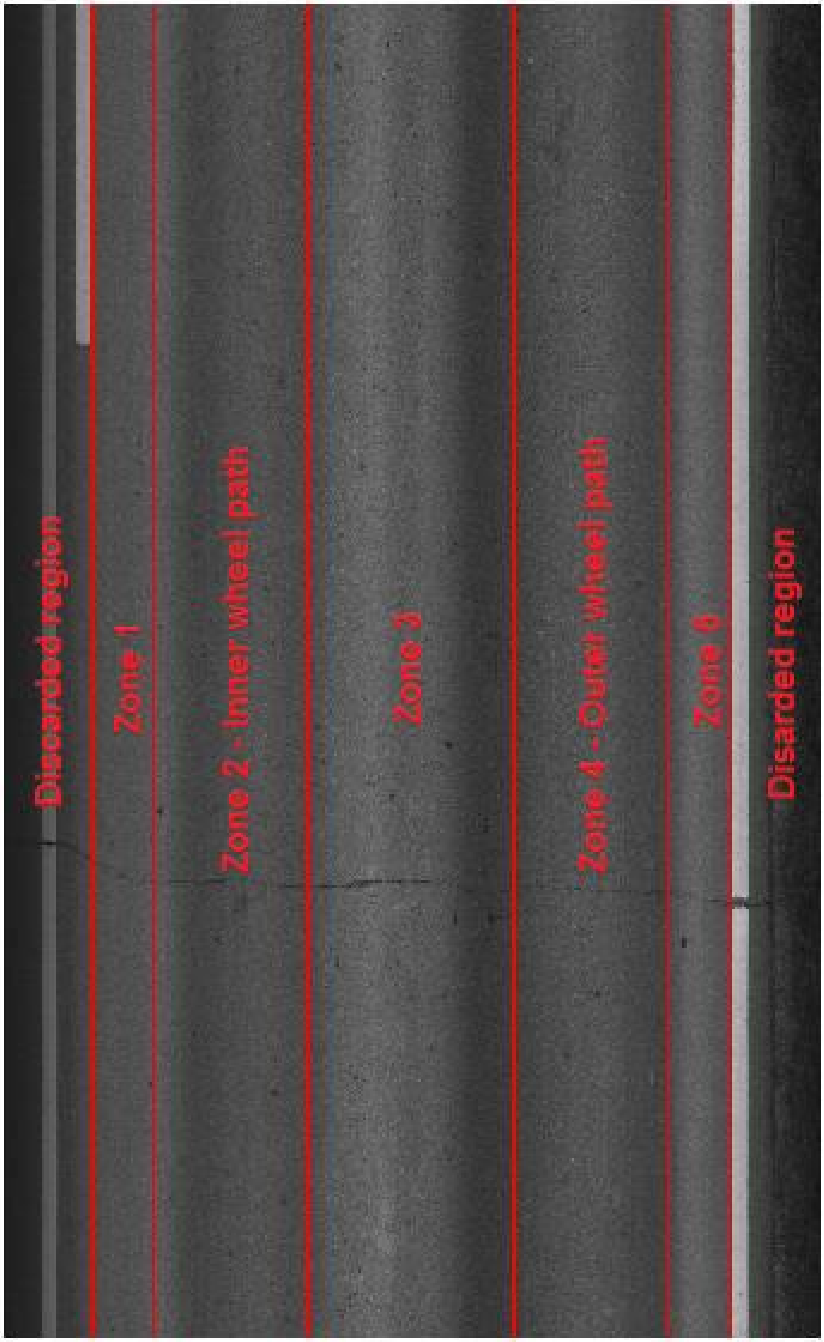
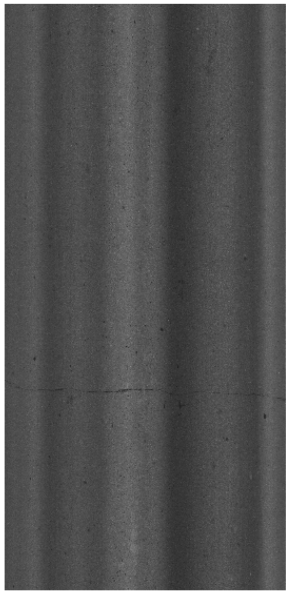
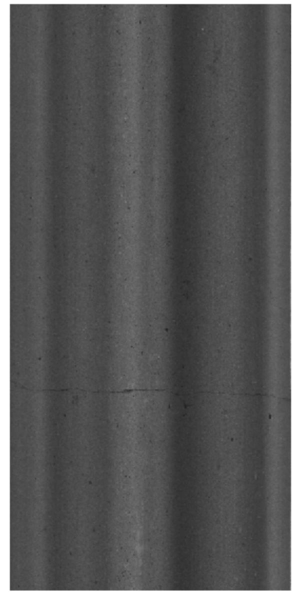


Figure 4.3: *Zones*



(a) Original Image



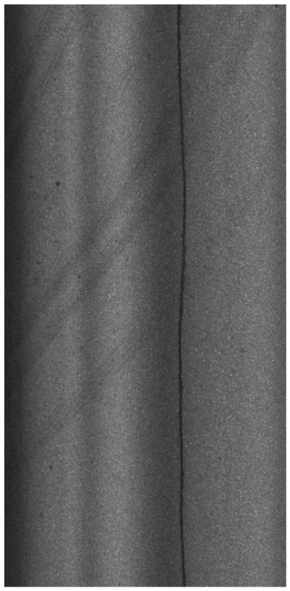
(b) Resized Image

Figure 4.4: *Transverse Crack after Resizing*

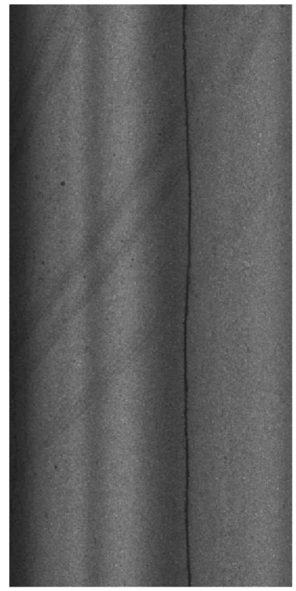
images and the corresponding resized images are shown in figure 4.4 and figure 4.5.

The classification of cracks into as part of cracked and uncracked is done using the thresholding technique. Thresholding is a very common technique and is used widely in image processing to pick out useful signal from a noisy background at lower computation cost [13]. The thresholding technique used here takes into consideration that the cracked pixels appear darker than the surrounding pixels in a gray scale image. A threshold is a local phenomenon because the lighting condition and other properties of the road vary widely across the whole image. Therefore it is almost impossible to set a single global threshold for the whole image. In the process being used here[3], for a transverse crack, the threshold is calculated along each column for a set of rows. For longitudinal cracks the threshold is calculated along each row for a set of columns. For each set the local threshold is calculated as a function of local mean and local standard deviation as:

$$\tau_{lt} = \mu_{lt} - \sigma_{lt} \tag{4.1}$$



(a) Original Image



(b) Resized Image

Figure 4.5: *Longitudinal Crack after Resizing*

where μ_{lt} is the local mean and σ_{lt} is the local standard deviation.

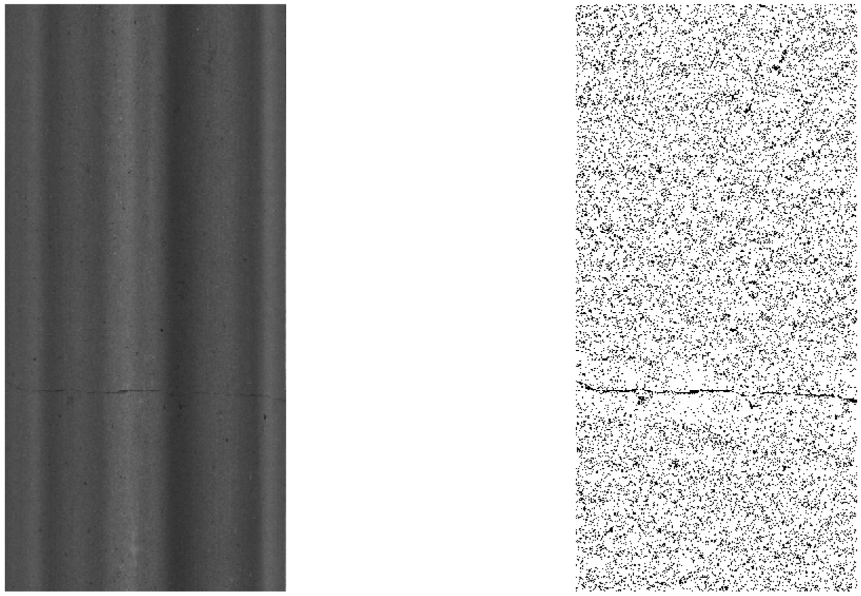
Depending on the local threshold a pixel p(x, y) in the set is classified as

$$\text{p(x,y)} = \begin{cases} 0 & \text{cracked if p(x,y)} < \tau_{lt} \\ 1 & \text{uncracked if p(x,y)} > \tau_{lt} \end{cases} \tag{4.2}$$

The output of thresholding is an image of ones and zeros, examples of which are given at figure 4.6 and figure 4.7

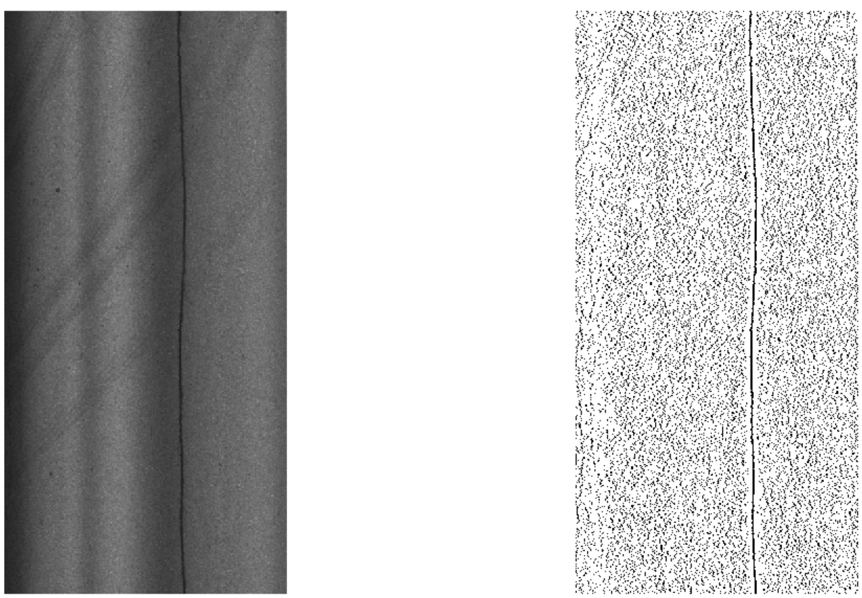
4.2.2 Line Detection

Line detection is the process of searching for linearity within the image. The thresholded image has a lot of uncracked pixels which are classified as cracked because of its low pixel value with respect to the surrounding, but these pixels tend to lack linearity, i.e. they won't be surrounded by any other pixels classified as cracks. Combining this with the fact that



(a) Grayscale Image (b) Thresholded Image

Figure 4.6: *Transverse Crack after Thresholding*



(a) Grayscale Image (b) Thresholded Image

Figure 4.7: *Longitudinal Crack after Thresholding*

the actual cracked pixels tend to be linear because of the linear nature of the crack, line detection is the easiest and computationally less expensive method of rejecting the unwanted pixels.

In the process being followed here[3] each pixel that has been classified as cracked from the thresholding, is checked for linearity. The range of linearity checked here is 3 pixels. Figure 4.8 explains the method.

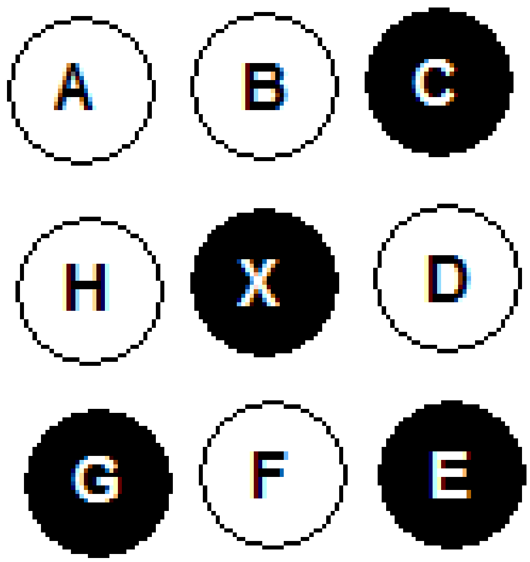
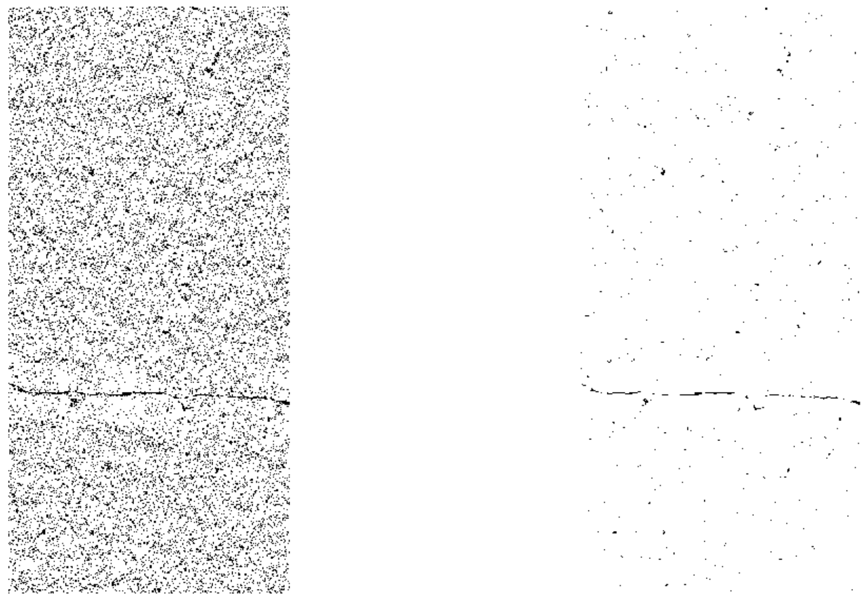


Figure 4.8: *Line Detect*

The pixel 'X' is checked for cracked linearity along 'AXE', 'BXF', 'CXG' and 'DXH'. If the all pixels are cracked in any of there directions, X is considered crack, else uncracked. In the example given X is cracked because of the linearity in 'CXG'. The range of 3 pixels gives satisfactory results on rejecting unwanted pixels and retaining the cracked pixels. Figures 4.9 and 4.10 shows the outputs of line-detect.

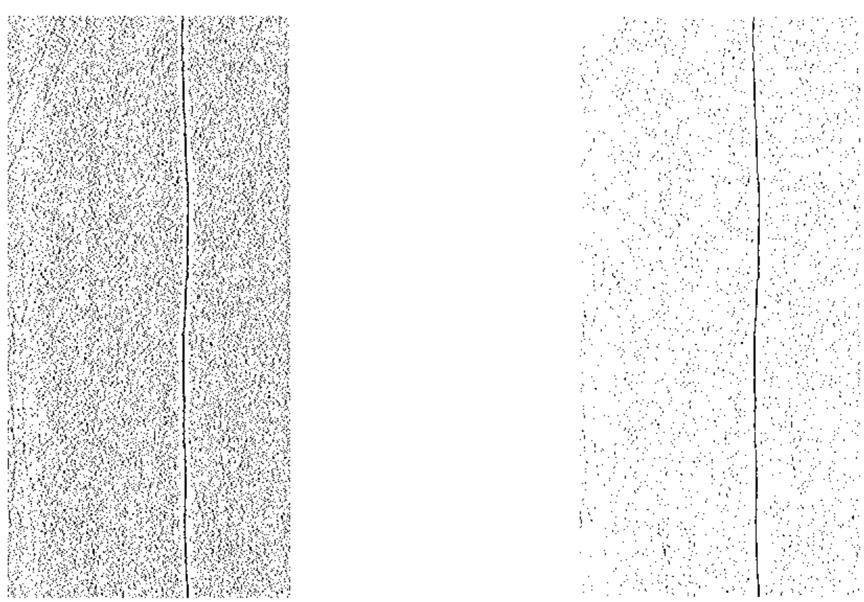
4.2.3 Scanning and Image Resizing

The lighting differences within the image and the line detection step tend to cause some of the cracked pixels to be classified as uncracked. The accuracy in the detection of cracked



(a) Thresholded Image (b) Line Detected Image

Figure 4.9: *Transverse Crack after Line Detect*



(a) Thresholded Image (b) Line Detected Image

Figure 4.10: *Longitudinal Crack after Line Detect*

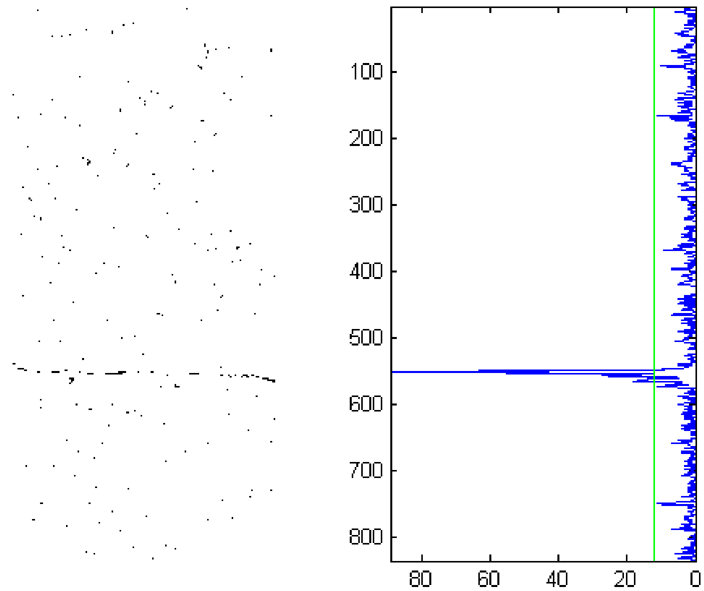


Figure 4.11: *Cracked Region Graph for Transverse Crack*

pixels is essential in calculating the crack features, which are discussed in the next chapter. To improve the accuracy, a scanning operation is done at the cracked region. As the first step towards this the cracked region within the image is identified. This is done by calculating the number of cracked pixels in each row for transverse crack and each column for the longitudinal cracks. A threshold is calculated based on the mean and variance of the number of cracked pixels as:

$$\tau_{cr} = \mu_{cr} - 2 * \sigma_{cr} \tag{4.3}$$

where μ_{cr} is the mean and σ_{cr} is the standard deviation.

The rows (columns in the case of longitudinal crack) which have number of cracked pixels above the threshold are classified as cracked row. The cracked region is identified based on this. Figure 4.11 and 4.12 shows the outputs of line detect, and the graphs used to identify the cracked region.

Once the region(s) of crack(s) is identified it is divided into sections of columns (rows in case longitudinal cracks). For each section the cracked pixels positions are identified and

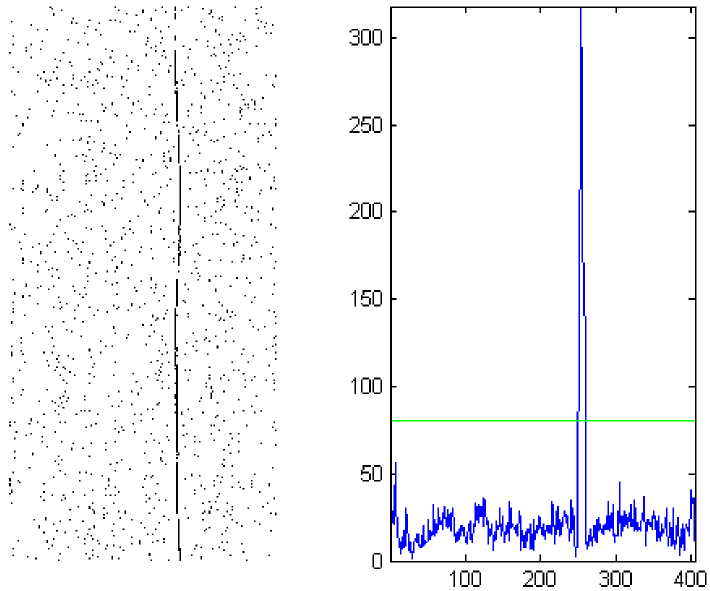


Figure 4.12: *Cracked Region Graph for Transverse Crack*

the corresponding pixels values are taken from the gray scale image. Mean and variance are calculated for these pixel values for each section. A lower and higher threshold value is calculated based on the mean and variance as:

$$\tau_{low} = \mu_s - \sigma_s \tag{4.4}$$

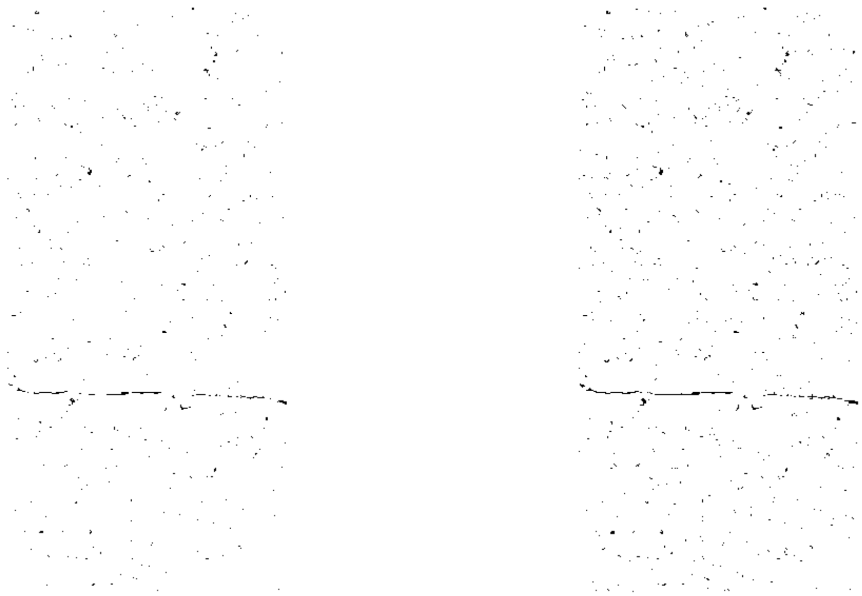
$$\tau_{high} = \mu_s + \sigma_s \tag{4.5}$$

where μ_s is the local mean and σ_s is the local standard deviation.

Depending on the two thresholds an uncracked pixel, p(x, y) = 1, in the set is classified as

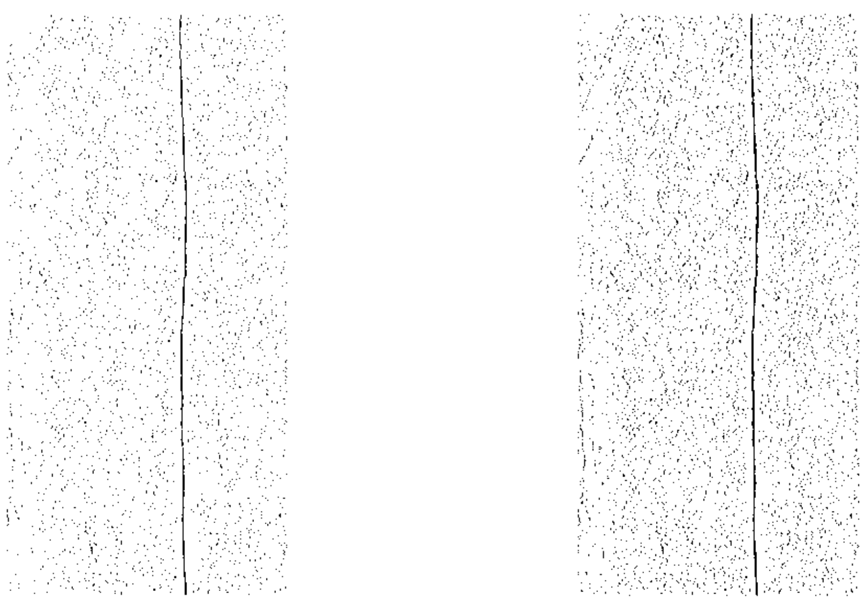
$$\text{p(x,y)} = \begin{cases} 0 & \text{cracked if } \tau_{low} < \text{p(x,y)} < \tau_{high} \\ 1 & \text{uncracked otherwise} \end{cases} \tag{4.6}$$

The scanned image is resized to the original size because it is essential to retain the actual resolution to accurately calculate the crack parameters. The resizing is done using bicubic interpolation . Figures 4.13 and 4.14 shows scanned and resized images.



(a) Line Detected Image (b) Scanned and resized Image

Figure 4.13: *Transverse Crack after Scanning and Resizing*



(a) Line Detected Image (b) Scanned and resized Image

Figure 4.14: *Longitudinal Crack after Scanning and Resizing*

4.2.4 Summary

In this chapter, we presented the preprocessing and detection steps for classifying the cracks as cracked and uncracked. The first step in this process involves finding the region of interest between the stripes. The second step is cracked pixel classification. For the ease of classification the image is resized and the pixel level classification by thresholding is done on the resized image. Line detection is done on thresholded image to reduce the number of unwanted pixels. The line detected image is then further scanned for cracked pixels. The image is then resized to the original size. The resized image forms the input for feature calculation steps which are discussed in the next chapter.

Chapter 5

Crack Feature Calculation

This chapter, outlines the methods proposed for calculating features of crack(s) within a pavement image. Features of a crack are its width, length, orientation and position, as discussed in section 2.3.2. Section 5.1 presents recognition of cracked sub-images and section 5.2 details the methods for calculating each of the features.

5.1 Identification of cracked sub-images

This section outlines the steps followed in identifying the cracked sub-images.

5.1.1 Sub-image level classification into cracked and uncracked

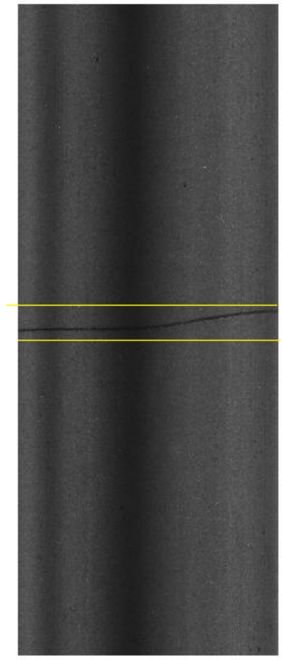
The region of crack has already been identified at the 'scanning and resiszing' step(refer section 4.2.3). This region is considered as made of many 32x32 sub-images [3]. The first step in sub-image level classification is to classify each of these sub-images into cracked or uncracked, based on the number of cracked pixels in it. If the number of cracked pixels within the sub-image is more than 10% of the number of pixels in the sub-image, the sub-image is considered cracked . This method of classification reduces the computational complexity in the next steps. The first step is merely an indication of crack within the sub-image. To further distinguish between the cracked and uncracked sub-images the properties of the sub-image is analyzed using principle component analysis (PCA). PCA is a very common method used in image processing for recognition and classification [13]. In our application we use it to extract features that can help us in distinguishing cracked and un-cracked sub-images. PCA is done on sub-images from the gray-scale image, position of which corresponds to the position of sub-images which passed the step1. PCA is initially performed on a set of 50 concatenated non-cracked images, and first three principle components are extracted. These three components capture around 96 % of the information in an image and can be used to adequately characterize the entire image . We then form two training classes of cracked and uncracked sub-images from different images. Each mean subtracted sub-image is projected onto the basis vectors and three weights, w1, w2 and w3, are extracted. These weights indicate the amount of energy present in each of the principal component directions in the vector space defined by the basis vectors. Thus we form two sets of cracked and uncracked weights. There are six distributions of weights totally, and each can be characterized using the probability density functions. As per central limit theorem, the weight distributions are observed to be normal with different means and variances [14]. In order to test a sub-image for the presence of a crack, its three weights, w1, w2 and w3, are obtained by projecting the mean subtracted sub-image onto the bases vectors. Each of these three weights is compared to the two pre-calculated distributions of cracked and uncracked weights. The probability of the test sub-image weights being closer to one distribution than the other is computed as a likelihood function, given as ;

$$L(w_i) = .5\log\left(\frac{\sigma^2_{c,i}}{\sigma^2_{uc,i}}\right) + \frac{w_i - \mu^2_{c,i}}{2\sigma^2_{c,i}} - \frac{w_i - \mu^2_{uc,i}}{2\sigma^2_{uc,i}} \tag{5.1}$$

where i = 1; 2; 3 and σ and μ are the variance and mean respectively.

For the threshold τ_l, given as

$$\tau_l = P_c/P_{uc} \tag{5.2}$$



(a) Grayscale Image

(b) PCA analyzed Image

Figure 5.1: *Transverse Crack after PCA*

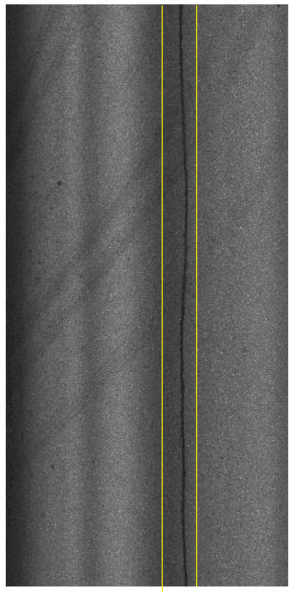
where tested values $P_{uc} = 0.9565$ and $P_c = 0.0435$,are prior probabilities that an sub-image is uncracked and cracked, the Bayes test [18] is given as ;

$$\text{Subimage} = \begin{cases} 0 & \text{if} \quad L(w_i) < \tau_l \\ 1 & \text{if} \quad L(w_i) > \tau_l \end{cases} \tag{5.3}$$

Here, value of 1 indicates cracked sub-image, while 0 indicates uncracked sub-image. Figures 5.1 and 5.2 show examples of transverse and longitudinal cracks after sub-image level classification. The regions of cracks are indicated on the gray scale image.

5.1.2 Post Processing-Closing and Filtering

After sub-image level classification, few sub-images which are not cracked may be classified as cracked due to anomalies on the road surface. However, these anomalies can be easily removed as they usually occur in very small clusters. A new, smaller image, is created from



(a) Grayscale Image

(b) PCA analyzed Image

Figure 5.2: *Longitudinal Crack after PCA*

the original image by identifying representative pixel of each sub-image. For this process, we take the first pixel of the sub-image as the representative pixel. A closing operation is carried out on the reduced size image with a structuring element of size 1×4 pixels while analyzing for transverse cracks, and 3×1 pixels for longitudinal cracks. The closing operation is common tool in image processing for removing unwanted specs from the image [13]. It consists of two steps, dilation and erosion. In the dilation process, subimages are elongated, and this remove small 'holes' which may occur between the subimages. During erosion the subimages are compressed back to their original size but the 'holes', which were closed in the dilation, remain closed. Transverse cracks can be considered as a linear segment which lie horizontally, hence a structuring element of size 1×4 is used for transverse crack. Similarly longitudinal cracks are considered as linear segment which lie perpendicular and a structuring element of size 3×1 is used. Additionally a filtering operation is done to remove unconnected sub images. During this operation, a linearity of '3' is used as a threshold to

(a) Crack after PCA

(b) Closed and Filtered Image

Figure 5.3: *Transverse Crack after Closing and Filtering*

indicate connections. That is, if a sub-image is not connected to two other sub-images in a linear direction the original subimage is rejected. Figures 5.3 and 5.4 show the results after the closing and filtering operation.

After the filtering operation, the image is rescaled to its original size, by substituting the sub-image at locations, where the surviving representative pixels remain after closing and filtering operation. It is important to note that, to calculate the crack features we dont need the pixel values of the cracks. All that we need are the pixel positions that are part of the crack. Hence, the final surviving sub-images with gray scale values are replaced by the corresponding binary valued sub-images which we get as output from scanning and resizing step (refer section 4.2.3). Example of this replacement is shown in figures 5.5 and 5.6.

(a) Crack after PCA

(b) Closed and Filtered Image

Figure 5.4: *Longitudinal Crack after Closing and Filtering*

5.2 Calculation of crack features

This section details the step and methods proposed to extract the features of the crack.

5.2.1 Identifying the Region of the Crack

The first step is to roughly identify where the crack lies. For this, the number of cracked pixels along each row is calculated. The rows with one or more cracked pixel are identified as a possible crack location. To separate out a crack or a set of small cracks, the rows which have at least one cracked pixel and which are not separated by more than 32 pixel-distances are grouped together. The same step as above is then carried out on the row groups along the column. This method roughly separates out a crack. The pseudocode for finding cracked region along row is given below.

Figure 5.8 and 5.9 shows cracks picked out from the images in figure 5.5(b) and 5.6(b) respectively.

(a) Closed and Filtered Crack (b) Binary Replacement

Figure 5.5: *Transverse Crack after Binary Replacement*

(a) Closed and Filtered Crack

(b) Binary Replacement

Figure 5.6: *Longitudinal Crack after Binary Replacement*

5.2.2 Division into blocks

Once the crack region is identified, the area around the crack is divided into blocks of size 32x32. This is to approximate and calculate the crack parameters with ease. The features like area and orientation can be approximated better using this method. This also helps in picking out occurrence of another crack very close to the crack being analyzed. Specifically, the starting of another crack due to sudden change in the orientation can be identified. Figure 5.10 and 5.11 show the division of cracked region into blocks.

5.2.3 Width of the Cracks

According to the AASHTO guidelines the width of the crack is to be calculated by averaging the width calculated at points 3mm apart. The proposed method for calculating the width is to find the line of best fit for each block based on the coordinates of the cracked pixels, and calculate the width based on the line of best fit. Co-ordinate of a cracked pixel is calculated

```
tmp   = 1:3344;
% Find the sum of all binary values along each row
pixs = 2048 - sum(image,2);
% i gives the index  where there is atleast one cracked pixel
i = find(pixs>0);
% use this index to find the rows at which cracks are present
lines = tmp(i);
% find difference between adjacent cracked rows
diff = lines(2:end) - lines(1:end-1);
% if the difference is greater than 32, denotes end of a crack
breaks = find(diff>31);
i     = length(lines);
% each element of break denotes starting of a new row in line
breaks = [breaks,i];
```

Figure 5.7: *Pseudo Code for Finding Cracked Region*

Figure 5.8: *Transverse Crack*

from the left-bottom of the block. A line is given by;

$$y = mx + c \tag{5.4}$$

where x and y are the co-ordinates of cracked pixels, calculated from the bottom left of the block. Given the coordinates of all the cracked pixels in the block, this can be written in matrix form as;

$$\mathbf{y} = \begin{pmatrix} \mathbf{x} & \mathbf{i} \end{pmatrix} * \begin{pmatrix} m \\ c \end{pmatrix} \tag{5.5}$$

where '**y**' is a vector of y co-ordinates and '**x**' is vector of x co-ordinates and '**i**' is a vector of ones. Here m and c are the unknowns, which represent the line of best fit. this can be solved as ;

$$\begin{pmatrix} m \\ c \end{pmatrix} = \begin{pmatrix} \mathbf{x} & \mathbf{i} \end{pmatrix}^{\dagger} * \mathbf{y} \tag{5.6}$$ [1]

[1] † - pseudoinverse

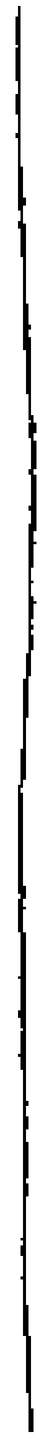


Figure 5.9: *Longitudinal Crack*

Figure 5.10: *Blocks Around Transverse Crack*

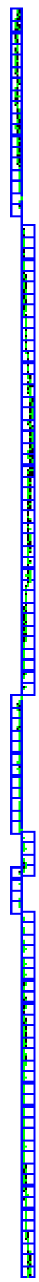


Figure 5.11: *Blocks Around Longitudinal Crack*

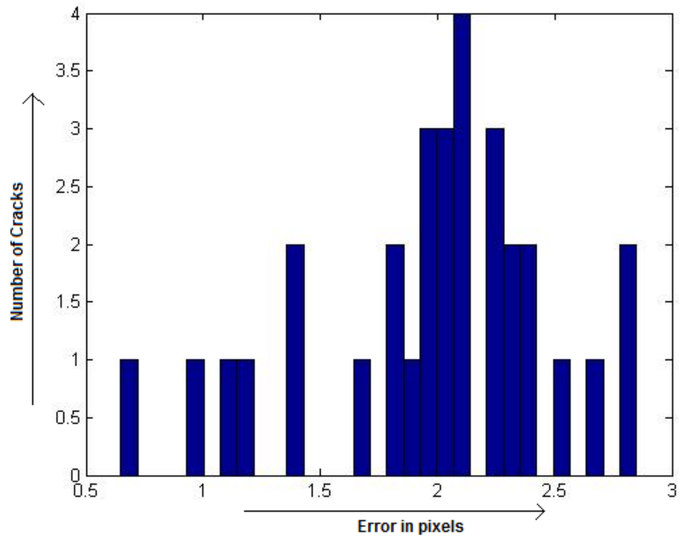


Figure 5.12: *Error Distribution*

Once the line of best fit is known for each block it length is calculated. This length can be approximated as the length of the crack within that block. The width of the crack can be approximated as;

$$Width = \frac{\text{`Num of Cracked Pixels'} * 1.93^2}{\text{`Length of line of best fit'} * 1.93} \quad (5.7)$$ [2]

where the numerator gives the area in 'mm^2', of the cracked pixel within a block, and denominator the length of the 'line of best fit' in 'mm'.

The width of the entire crack can be approximated as;

$$Width = \frac{\sum_i w_i}{\text{number of blocks}} \quad (5.8)$$

The width calculated by averaging the width of each block has been compared with the width calculated at points $3mm$ apart[3], and error has been calculated. It has been found that the error averaged around 2 pixels. Figure 5.12 shows the error distribution.

[2] With current available resolution, each pixel represents an area of $1.93 \times 1.93mm^2$ on the pavement, but the AASHTO guidelines require it to be $1 \times 1mm^2$

[3] Since the current image resolution is $1.93 \times 1.93mm^2$, sampling has been done at points at $3.86mm$ apart

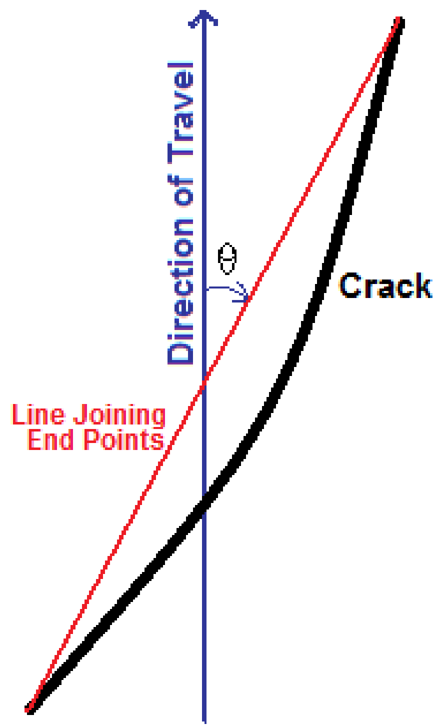


Figure 5.13: *Orientation of a Crack*

5.2.4 Orientation of the Cracks

The orientation of the crack, as per the AASHTO guidelines, is the angle between the direction of travel and the line joining the ends of the crack. Orientation of a crack is explained in figure 5.13. Within an 'identified crack', co-ordinate of a cracked pixel is calculated from the left-bottom of the cracked region. The pixel closest to left-bottom of the region is regarded as the bottom end of the crack and the pixel farthest from the left-bottom is considered the top end. If (x_1, y_1) and (x_2, y_2) are the bottom and top end of the crack, respectively, then the orientation of the crack θ is given as:

$$\theta = \arctan\left(\frac{y_2 - y_1}{x_2 - x_1}\right) - 90 \tag{5.9}$$

Figures 5.14 and 5.15 shows the lines joining the end points of cracks.

Figure 5.14: *Line Joining End Points of Transverse Crack*

5.2.5 Length of the Cracks

The length of the crack is the displacement between the two ends of the crack. The ends of a crack is found out as given in section 5.2.4. If (x_1, y_1) and (x_2, y_2) are the bottom and top end of the crack, respectively, then the length of the crack l is given as:

$$l = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{5.10}$$

5.2.6 Position the Cracks

The position of the crack are the coordinates of the midpoint of the line joining the crack terminuses, calculated from the shoulder of the road and the starting point of the collection point. Shoulder of the road is the right side of the pavement-image, and the starting point of the collection is the bottom of the pavement-image. If (x_{cr}, y_{cr}) are the co-ordinates of the right-bottom of a cracked region and w_{cr} the width, then the position (x_{crk}, y_{crk}) of the crack is given as:

$$\begin{aligned} x_{crk} &= x_{cr} + w_{cr} - \frac{(x_1 + x_2)}{2} \\ y_{crk} &= y_{cr} + \frac{(y_1 + y_2)}{2} \end{aligned} \tag{5.11}$$

where, (x_1, y_1) and (x_2, y_2) are the endpoints of the crack(refer section 5.2.4).

Figure 5.15: *Line Joining End Points of Longitudinal Crack*

5.3 Summary

The features of a crack are its width, orientation, length and position. The calculation of these features have been detailed in this chapter. The crack is divided into blocks of size 32×32 pixels. The width of the crack is approximated from the width of the crack in each block. The orientation is calculated from the line joining end points of the crack. The length and position of the crack is calculated from the co-ordinates of the end points of the crack. The next chapter will talk about the software implementation of crack detection system.

Chapter 6

Crack Detection Sytem Implementation

A pavement analyzer and crack classifier has been implemented on Visual Studio .NET 2005 for Windows platform. This is an application for Windows OS, which can analyze the pavement images and generate report on the condition of the road. The application was developed based on a technique for crack detection on pavement surface, and classification into sealed and unsealed [3]. This chapter gives an overview of the system and the modules in the software implementation.

6.1 Overview of the System

'Pavement Analyzer and Crack Classifier' is a Windows application which can, depending on the user input, browse through a directory and its sub-directories, and pick pavement images, in jpeg format, for analysis. The application can analyze the pavement images for the presence of cracks and classify the cracks into 'Sealed' and 'Unsealed'. The unsealed cracks are open cracks and the sealed cracks are the cracks which have already been treated. Refer section 2.1 for further information on sealed and unsealed cracks. The application can also generate reports on the status of a route or pavement image. The report generation is further discussed in chapter 7.

The software code for the application is developed on Visual Studio .NET 2005, using

C, C++, OpenGL and Windows Forms Application classes. The implementation consists of the following modules:

1. Front end : This module consists of the UI, associated APIs and the image reader.
2. File Parser : The parser can read .D01 files, provided by KDOT, and pick out information about image and GPS position at each mile marker.
3. Image analyzer and crack classifier : This module analyses an image for presence of cracks and classify the cracks into ‘Sealed’ or ‘Unsealed’.
4. Report generator : Generates a ‘Detailed’, ‘Status’ or a ‘KML’ report. Reports are discussed further in chapter 7.

6.2 Software Information and Organization

This section will list and discuss the modules in the software implementation.

6.2.1 Front End

The front end of the implementation consists of the User Interface, Browser and the Image reader. A picture of the UI is given in figure 6.1. The UI is built on ‘Windows Forms Application classes’.The UI gives the user, the option for generating ‘Detailed Report’, ‘Status Report’ or a ‘KML Report’. The user is required to give the path to output folder and the folder which contains the .D01 files. The .D01 files contains image name and GPS co-ordinates at each mile marker for a route. Once the user presses the ‘Create’ button, he/she will be given the option to specify the directory at which to browse for the pavement images. The Browser, written in C, browse through the specified directory and its sub directories and identifies the images which are in ‘jpeg’ format. These images are given to the ‘Image reader’. The ‘Browser’ also identifies the .D01 files for parsing. Classes and functions in ‘OpenGL’ has been used for the ‘Image reader’. ‘Image reader’ opens the jpeg image and reads the contents to a bit stream buffer in raw gray scale format, with eight bit

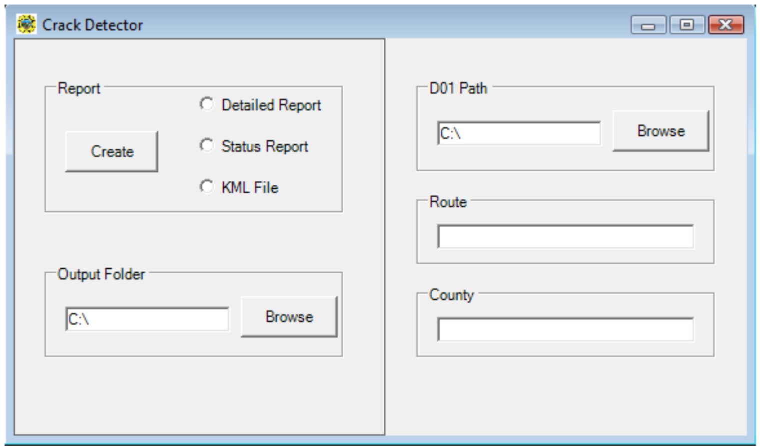


Figure 6.1: *UI*

representing one pixel. The front end is Windows' specific, that is, it calls function available only on Windows platform.

6.2.2 File Parser

The file parser reads the .D01 files. The .D01 files are provided by the KDOT. For each route a separate .D01 file is provided. The file contains, among many other information, the route number, the county number, name of the image taken at each mile marker and GPS co-ordinates at the mile marker. The parser reads these information from the .D01 files. The information from the parser is the stored onto a linked list for easy access by other modules. The parser has been written as platform independent C function, that is, it can be complied and used on any other OS apart from Windows.

6.2.3 Image Analyzer and Crack Classifier

This is the largest module in the system. It contains a set of functions written in platform independent C language, which help in analyzing an image and classifying the cracks found [3]. The gray scale image, from the image reader, is analyzed in this module for the presence of crack. The cracks, if present, are then classified into 'Sealed' and 'Unsealed'. Figure 6.2 shows the steps in images analysis and crack classification.

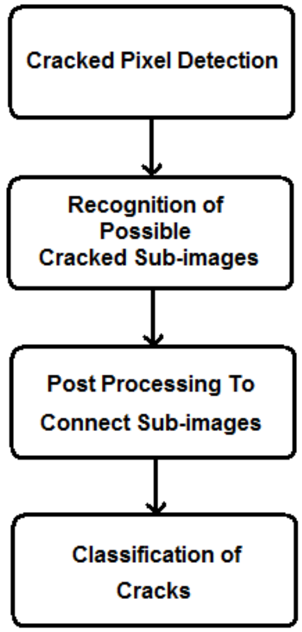


Figure 6.2: *Steps in Image Analyzer and Crack Classifer*

The 'cracked pixel detection' step has two main operations; classification of pixels into cracked and uncracked, and line detection to filter out unconnected pixels and present only the relevant cracked pixels. These two steps are detailed in sections 4.2.1 and 4.2.2. The module has two separate function calls for the pixel calssification and line detection. At the recognition step, the image is considered as made of sub-images of size 32×32 pixels, and each sub-image is classified as 'possible cracked' or 'uncracked' depending on the number of cracked pixels in it. The 'possible cracked' sub-images are further analysed using principle component analysis(PCA) technique, where weights associated with cracked/uncracked nature of the sub-image are extracted. These weights are compared with the precomputed weights of cracked and uncracked sub-images to find the exact nature of sub-image. In the steps following PCA, only the cracked subimages are considered, rest of the sub-images are discarded. A closing operation, followed by a filtering operation is carried out at the post processing step to remove isolated cracked sub-images and connect subimages which are not well connected. The recognition and post processing steps are discussed in detail in section 5.1. After the post processing operation, the locations of cracks in the image are identified. At the classification step, the cracks are classified as transverse or longitudinal based on their orientation. The cracks are further sub-classified into sealed or unsealed using a fourier transform based approach[3][25]. The fourier spectrums of the cracks are analysed for the classification. The module provides a single function call for the recognition, post processing and classfication steps.

6.2.4 Report Generator

The report generator can create three types of report, based on the user input. This module can generate a detailed report giving the name, mile marker and number of each category (sealed and unsealed) of cracks for every image. A status report can also be generated for each route, which gives the total number of cracks in each cateogory found in that route. The module can also create KML files which can be viewed on 'Google Earth' [19]. The KML files will contain the GPS locations of the crack, viewed as KDOT icons on 'Google Earth'. The KML file also provides the option of viewing the pavement images by clicking on the KDOT tags.

6.3 Performance

The performance of the system has been tested on a large amount of image data. The system has been successful in identifying and classifying the cracks. Each image takes about 5 seconds of processing time. The reports are being generated as per the requirement without any error.

6.4 Summary

This chapter, gave an overview of the crack detection system. The modules involved in the software implementation haven been discussed. Reports generated by the system helps the user to make useful interpretation on the condition of the pavement. The types of report are explained in the next chapter.

Chapter 7

Reporting and Visualization

Reports generated by the crack detection system helps the user in making useful and effective interpretation of the condition of the pavement. This chapter will detail the reports being generated from the crack detection system.

7.1 Auto Report Generation

Based on the images that it has analyzed, the 'Pavement Analyzer and Crack Classifier' generates one of the three types of report. The user can give preference on the type of report that has to be generated, while running the application. The report generation is completely automatic, and the report is either printed out onto a excel sheet or a kml file is generated. The reports that can be generated by the application are;

1. Detailed Report
2. Status Report
3. KML file(Google Earth)

7.1.1 Detailed Report

The detailed report will contain the information of all the images that has been analyzed by the tool. The detailed report will contain the image name, its route number, county number, number of sealed cracks in the image, number of unsealed cracks in the image and

	A	B	C	D	E	F	G
1	Image	Num of Sealed	Num of Unsealed	County	Route	Mile Marker	
2							
3							
4	1P001535.	1	0	89	240	12.584	
5	1P012419.	0	0	99	40	1.078	
6	1P012439.	0	1	99	40	1.157	
7	1P012459.	0	0	99	40	1.236	
8	1P012659.	1	0	99	40	2.024	
9							
10							
11							

Figure 7.1: *Detailed Report*

its mile marker. The detailed report is printed to a excel sheet. Example of a detailed report is give in figure 7.1

7.1.2 Status Report

The status report gives the user an idea about the condition of each route. The status report contains list of all the routes, its county number, and the number of sealed and unsealed crack within that route. The status report is printed to a excel sheet. Example of a status report is give in figure 7.2

7.1.3 KML Report

KML report utilizes the tool 'Google Earth' to show pavement images and its location [19]. This report is generated as a .KML file which can be viewed on 'Google Earth'. An example of the KML report is shown in figure 7.3. A KML report is generated for a single route. The user will have to specify the route number and county number of the route, of which the report has to be generated, while running the 'Pavement Analyzer and Crack Classifier' tool. On the 'Google Earth' the route will be highlighted and the GPS location of the images will be marked by a KDOT tag. Further details at each GPS position can be visualized by clicking on the tag. A window will be opened, which will show the image, route and county number and the date at which the image has been take. It also has a provision for showing

	A	B	C	D
1	County	Route	Num Sealed Cracks	Num Unsealed Cracks
2				
3				
4	99	40	50	20
5	3	70	3	24
6	75	240	10	0
7	89	240	30	2
8	70	310	12	23
9	23	590	43	9
10	66	630	27	10
11	70	680	11	122
12	3	73	3	83
13	70	750	0	62
14	44	920	19	35
15	70	1700	15	31

Figure 7.2: *Status Report*

the severity and the type of crack present within the image.

7.2 Summary

The chapter, detailed the types of reports which can be generated using the 'Pavement Analyzer and Crack Classifier' tool. The detailed, status and KML reports have been discussed. Example images of each report type have been given. The crack feature measurement system based on AASHTO standard and the the 'Pavement Analyzer and Crack Classifier' tool still has scope of improvements. Next chapter, will discuss about the improvements that can be made and other future work.

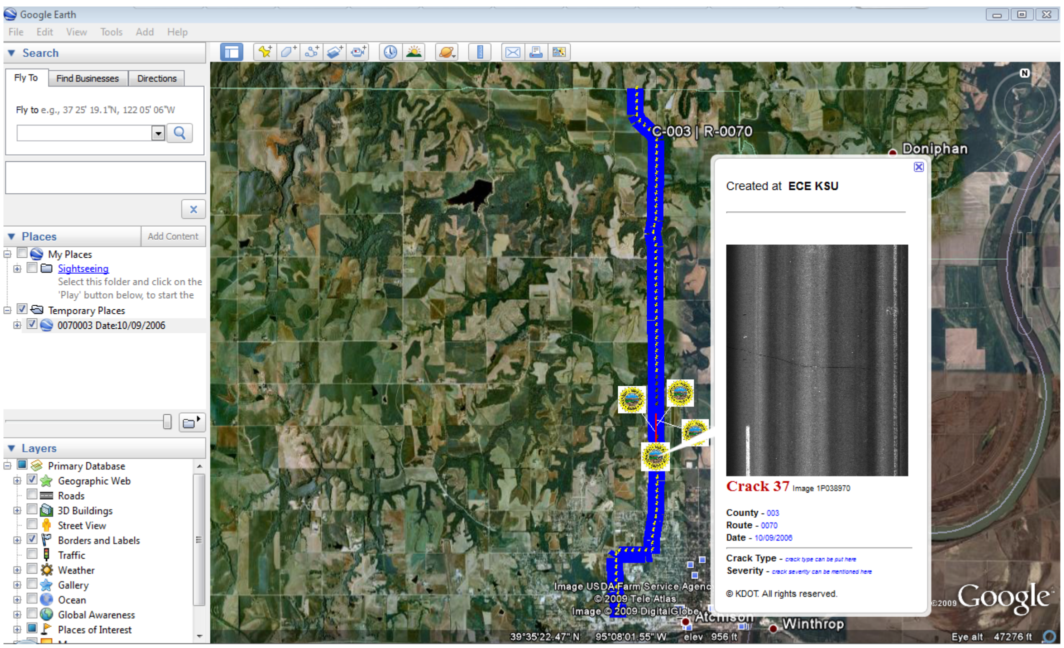


Figure 7.3: *KML Report*

Chapter 8

Conclusion and Future Work

This chapter, discusses the key contributions of this thesis and possible future research directions.

8.1 Summary of Key Contributions

In this thesis, we presented, for the first time, an automated crack analysis system based on the AASHTO guidelines. Current crack analysis methods, suffer from inconsistencies in crack detection and classification. The AASHTO standard is working towards standardizing methods for quantifying cracking distress in asphalt pavement surfaces. The system is fully automated, and does not require human interaction to detect and analyze the cracks on the road surface. A standardized automated system will help reduce the inconsistencies and errors that may occur during the analysis and classification. The first stage of the system is image capture and storage. Images of the road are captured by an image capture vehicle built by 'International Cybernetics Corporation Digital Image Data Collection System'. For undivided highways images are collected only in one direction and for divided highways the images are collected from the outside lane. The images of size 3344×2048, are captured for every $8m$ of the highways at $60mph$. The image resolution reaches $1.93mm$ for every pixel. The images are classified based on the county and route to which it belongs, and then stored on a database. In the next stage, the images are retrieved from the database, and the region between the lane separation and shoulder stripes is identified. Only those cracks which fall within this region is analyzed and classified. The region is then divided into five different zones based on the dimensions provided by the AASHTO guidelines. The zones help identify the wheelpaths on road. The cracks on the wheelpaths affect ride quality and hence are considered more problematic than the rest. The region between the stripes is then reduced to 25% its original size for the ease of computation in the next steps. Through steps of thresholding, line detect and scanning, the gray scale image is converted to binary with 'zeros' representing cracked pixels and 'ones' representing uncracked. After this the binary image is rescaled to the size of the original gray scale image. PCA analysis at the sub-image level is carried out, on gray scale image, to find the cracked sub-images. Closing and filtering operation is then carried out on the image to establsih connectivity between the cracked sub-images and to identify the crack(s). In the final step of identifying cracks, the output from the filtering operation is replaced with its binary counter part. Final stage of the proposed method is crack feature calculation. The region around the crack is divided into blocks of 32×32 to approximate and calculate the crack parameters with ease. The width is approximated by the average width of crack in each block. The end points of the cracks are found, and the orientation of the crack is calculated by the angle between direction of travel and the line joining the ends of the crack. Length of the crack is the displacement between the ends of the crack, and the position of the crack is calculated from the midpoint of the line joining the end points.

The performance of the system has been tested on a large amount of image data. The system has been successful in identifying the cracks and calculating the crack features.

8.2 Future Work

Reporting

Data interpretation is essential to bring out meaningful results from the analyzed images. Depending on the orientation of the cracks, they can be divided into transverse, longitudinal and pattern. The pattern cracks are further classified into five zones depending on the position. For .1km section of road (this will be equivalent to 16 images with the current resolution of 1.93mm per pixel), the severity and extent are calculated for each category of crack. Severity of cracking is calculated as the average width of cracks in each category, and the extent of cracking is the total length of all the cracks in each category. Reporting is done for each .1km section of the road, giving the extent and severity of cracking in each category, for that section.

The calculated extent of cracking, in $meters$, in each category, is reported as the extent of cracking in that category. The severity of cracking, in mm, in each category, is reported as the severity in that category. The indexes may be normalized to the scale of 0 to 10, with 10 representing most severe or extent. If the extent or severity, is equal to or greater than the average value of the worst 10% of extent or severity calculated so far, it is given the value 10. The rest can be normalized based on this. A more generalized cracking indexes can be reported by combining these normalized values.

Validating

The accuracy of the sytem proposed can be validated if we have the ground truth data. The features of a crack measured from propsed system can be compared against the values available in the ground truth data.

Conversion to C code

To increase the speed of the system and to make a useful tool out of the automated system, it may be converted to C code. This will help in making a more effective tool, which can be distributed and used by end users.

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