Vision Guidance System for the Robotic Roadway Message Painter

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Waqas Ahmad

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Dedication

Dedicated to family

Abstract

Roads are used as a way of transportation and communication in every part of the world. Road markers are painted on the roads for safety, information and caution purposes. Road markers are mainly used to assist drivers with vital information and caution. The process of painting new and existing roadway markings (turn arrows, STOP messages, railroad crossings, etc.) is an important maintenance task. The Minnesota Department of Transportation (MN/DOT) estimates that over 75% of symbol and message painting is the repainting of existing markings [1]. It would be extremely valuable for an automated painting system to have a vision guidance capability whereby an existing marker could be repainted accurately with little operator input.

A vision system capable of identifying existing painted pavement markings and determining their coordinates, dimensions, location, and orientation would be a very useful tool. The information regarding the pavement markings could then be passed to a robotic painting device (currently under development) to enable it to accurately repaint the marking. This would significantly improve the capability of the device to repaint existing pavement markings.

Eventual users of a device using this technology could be city, county, state, federal government agencies and private companies or contractors. It will allow improved safety, reduced cost and less time to maintain existing road markers as well as draw new ones.

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Chapter 1 : Introduction

This thesis report is the study of developing a vision guidance system for the robotic roadway message painter. The goal of this study is to develop a system using images for repainting road markers that can be used by the city, county or state transportation authorities. This would be helpful to these authorities in repainting road markers, thus reducing the labor, cost and time duration spent in such road maintenance projects. The following section will provide the motivation behind this study.

1.1 Motivation

Roads are used as a way of transportation and communication in every part of the world and road markers are painted on the roads for safety, information and caution purposes. Road markers play a definite and key traffic control function. In most of the cases, they are supportive and supplemental to traffic signs or signals already present there as well as produce results that cannot be achieved with the help of other devices. In a nutshell, road markers serve a very effective way of conveying the regulations, laws and warnings that could not otherwise be made clearly understandable.

Road markers have their limitations, such as they become obscured by snow or dirt, and my not be clearly visible under rainy conditions or fade off due to high volume of traffic on the particular road [1]. Regardless to these limitations, they still have a strong edge over other systems to provide correct information, conveying warnings without diverting the attention of the drivers from the road under favorable conditions. [2]

Road markers play an important role against the traffic crashes, and significantly may reduce single or multiple road crashes if followed properly. [3] The National Highway Traffic Safety Administration (NHTSA) provides crash statistics gathered from police cash data throughout the nation as shown in Table 1.1.

Table 1: Change in U.S. Crash Statistics from 2002-2011 [2, 3]

Statistics	2002	2011	Change from 2002 to 2011 (%)
Total Crashes	6,316,000	5,338,000	-15.5
Fatalities	38,309	32,367	-15.5
Injuries	2,926,000	2,217,000	-24.2
Resident Population	287,625	311,592	8.3
Licensed Drivers	194,602	211,875	8.9
Registered Motor Vehicles	225,685	257,512	14.1
Vehicle-miles Travelled (billion)	2,856	2,946	3.2
Fatalities per 100 million VMT	1.51	1.10	-27.2
Injuries per 100 VMT	102	75	-26.5

Table 1 shows the trends in the U.S. traffic crashes and related transportation from 2002 to 2011. It shows a decline in the traffic crashes; given the fact that the population, number of drivers, registered motor vehicles and vehicle-miles travelled (VMT) have increased over the past 35 years. Total number of crashes as well as the fatalities and injuries has been significantly dropped by a percentage of 15.5, 15.5 and 24.2 respectively. Improved safely features such as pavement markings, road markers and regulations over the years in the traffic safely have been one of the major factors in the improvement of these statistics. [4]

Road markers are used as an important tool to assist drivers with information and caution. The process of painting new and existing roadway markings (turn arrows, STOP messages, railroad crossings, etc.) is an important maintenance task. The painting / repainting techniques vary at state, county and city levels. Machines as well as sometime hand painting techniques such as using stencils or embedding the decals in the roads are used for the purpose.

The process of painting road markers needs to be repeated frequently after certain period of time, depending upon the condition, visibility and clearness of the marker to make sure the safety of drivers on the road. These time variations are different for repainting the road markers and range over the span of time period ranging from one year to three years.

Although, these paint jobs may seem trivial, much care is needed for painting existing as well as new roadway markers and it involves a great deal in terms of the accuracy of the paint job to lower the risk factor for the safety of the paint crew workers. [4] It is desirable that road marker to be repainted on the exact same location as the existing one or desired location as per requirements. A lot of time and money in terms of labor is used for such jobs and an automated paint system would help lower the risks involved in painting the road markers and reduce cost and labor as well.

Road markings can be divided into three different categories: category A includes mostly the lines painted on the road such as center lines etc., category B contain those markings which are cautionary bold lines such as thick median diagonal strips or thick stop sign lines etc., category C include road markers such as arrows and different shapes. In this project, we are mainly focused on category C, and will discuss the details in the subsequent chapters. Road markers contains various arrows such as left, right, straight, left-straight, right-straight etc., and usually these markers are painted using a stencil and spray gun or using thermoplastic.

Various different kind of equipment is used on the paint trucks depending upon the functionality, size, and type of work. This is the main reason for variation in the results in paint job due to variation in truck set-up and methods of performing these jobs. The process of painting is not uniform itself and as a result substandard road makers / pavement markings can often be found.

One common method for painting shorter lines or road makers is doing it manually as shown in Figure 1.1

Figure 1.1: Maintenance Painting Manually [4]

The road markers are painted/ re-painted with already established system using trucks which involve less work. A nozzle is mounted in the front of the rear axle of the vehicle, so that it is much close to the center of the truck and in that way, it is easier to control its position. Being close to the center means that there is less sensitivity while turning and therefore, more control during the paint job. Painting vehicles are equipped with various kinds of equipment that include tanks of paint, glass beads, hydraulic motor, air compressor, thermoplastic sheets, the nozzle and spraying tools. A much refined paint truck is shown in the Figure 1.2.

Figure 1.2: Road Marker Painting using Truck [5]

The main method for painting all the detailed arrow signs that includes but not limited to straight arrows, left arrows, right arrows, bars etc., is by using stencils as shown in Fig. 1.3. Due to the nature of paint job as it has to be more detailed, clean and sometime exactly on the same spot as the original marker, it is preferred to perform such jobs during the day time over the weekend as compare to the nights. However, day time is much busier in comparison to the night and required extra precautionary steps for the safety of the workers and the motorists as well.

The draw backs for this method are setup time as its takes lot of time to setup the location, job time to perform the actual painting, dry time to let the paint job completely dry and lastly, the cleanup time in which all the materials such as construction zone signs, speed limit indicator, diversion symbols, and orange cones are removed. One such depiction is shown in Figure 1.3 in which worker using orange cone and stencils for the paint job.

Figure 1.3: Road Marker Painting using Stencils [6]

Another method used for painting the road markers is by applying the arrow decals or ceramic buttons as shown in Figure 1.4. However, ceramic buttons are not an approved marking material due to the fact that they are not a retro reflective material and therefore provide poor nighttime visibility [7].

Figure 1.4: Worker applying arrow decal [7]

The decals are sometime embedded in the road permanently, which is time and labor intensive work. It takes time to dry up the arrow decals and when there is any change occur in the traffic patterns, it is hard to remove them and replacement is not easy as compared to the painting the road markers. The drawback of this technique is the labor cost, dry time and sometime it is hard to make a change once the job is done. Polymer stickers or embedded arrows are also placed on the road. This provides a long term solution; the average decay is less than the painted road makers [7].

The cost and time efficiency of the existing road marker painting systems are not optimal and even cause life threatening risks to the crew performing the job during busy hours on the road.

Minnesota Department of Transportation or MN/Dot has been using the similar techniques for several years and in which it uses standard size road marker templates for the painting purposes as shown in Figure 1.5.

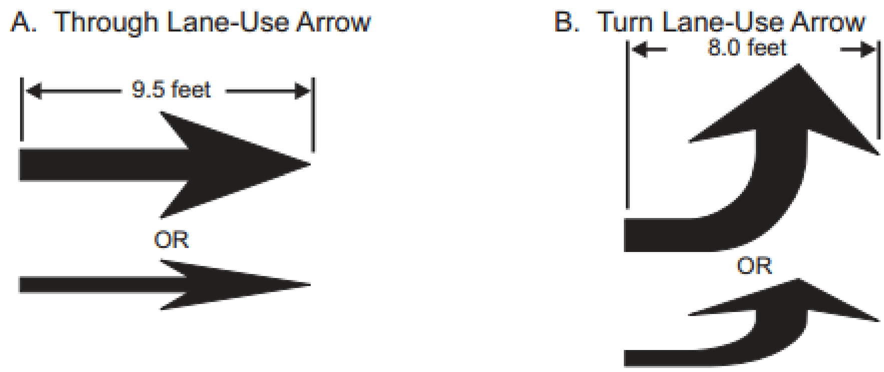


Figure 1.5: Examples of Standard Arrows for Pavement Markings [8]

These road markers sizes may be reduced approximately one-third for low-speed urban conditions; larger sizes may be needed for freeways, above average speeds, and other critical locations. Further information regarding the pavement markings is available in the MN/DOT “Standard Signs Manual” [8] and the FHWA (Federal Highway Administration) "Standard Highway Signs and Markings" book [8], may be used as determined by engineering judgment to supplement signs and/or to provide additional emphasis for regulatory, warning, or guidance messages as shown in Appendix A.

1.2 Summary of Previous Work

The research has been conducted for the two previous NATSRL (*Northland Advanced Transportation Systems Research Laboratory)* projects related to robotic pavement painting in the Department of Mechanical and Industrial Engineering at University of Minnesota, Duluth.

The project was started with an initial feasibility study [9] of the robotic painting of the pavement markings. A prototype was designed in the later stages to successfully demonstrate the capability of the robotic arm to paint the pavement markings [10] as shown in the Figure 1.6.

Figure 1.6: Left: Prototype Roadway Painter, Right: Results from the Painter [9]

This further lead the research to a new level of automating the road marker painting in by a robotic arm with the minimal operator efforts in a smooth, cost effective and timely manner. The robotic arm is mounted in front of the truck and with the help of imagery obtained by the camera, the operator can snap the pictures and then the system would automatically determine the shape and size of the road marker need to be re-painted. The coordinates are then passed to the robotic arm which is equipped with the spray paint gun to precisely repaint the road markers.

1.3 **Expected Benefits and Users of this Research:**

One of the advantages of automatic robotic paint arm is to improve the efficiency of current pavement marking techniques. Furthermore, most of the pavement marking includes repainting of existing road markers, thus automated robotic arm painting will save more time and money. The potential benefits are not limited to the time but also the cost and the labor intensive work. In a long run, that can save lot of money to the agencies at state, county or city level who use different techniques for painting pavement markings. Private contractors and government agencies such as DOT can be the end users of this product.

1.4 **Safety of the Marking Crew**

Most of the pavement markings or road markers are done with traffic not far from the workers. Only in some situations, such as when the newly constructed road is not open to traffic, can they work freely without any fear of oncoming traffic. Studies suggested increased number of road worker injuries over the past years due to the increased volume of motor vehicles. [3] This trend is alarming for the safety of workers and the proposed system will help reduce such instances as the road worker practically would not need to step outside of his/her vehicle.

1.5 Improved Efficiency

Over the years, the amount of time spent on repainting the road markers/ pavement marking has significantly increased due to the large number of motor vehicles on the roads. [3] An automated road marking paint job will significantly reduce the time, labor and safety, and eventually increase the productivity of the overall process.

1.6 Reduced Traffic Crashes

Road marking is done during day with the flow of traffic going on with the help of additional vehicles providing warning signs and diverting traffic by placing orange cones. However, according to a survey conducted by VDOT in 2001 [2] for the safety of the crew members, the average time spend by the crew members on the roads was 157 days and one crash occurred. From the period from 1997 to 2002, [3] there were nine crashes involving crew members and if we include the crew from the contactors these numbers go even higher.

1.7 Thesis Outline

Before further explaining the design and development of the vision guidance system for the robotic roadway message painter, a brief background about image processing techniques is described in chapter 2. Chapter 2 also provides the details of the working of the vision system. Exiting methods being used for road marker detection are briefly discussed and the use of a vision guidance system for the robotic roadway message painter is also described.

In chapter 3, the system design is discussed in detail which provides an understanding of pre-processing techniques for images. Different problems with the images regarding the artifact removal are discussed along with perspective overlay techniques. Coordinates computation and image extraction techniques are also discussed in chapter 3.

Chapter 4 describes the results and analysis regarding the test procedures used.

Chapter 5 concludes the discussion along with some future work and a summary of the research work.

Chapter 2 : Vision System

The main focus of this research is to reduce the time and cost for repainting road markers with the help of an automated system. The time required for such jobs is lengthy and eventually adds up to high labor cost, materials cost and delay cost due to unforeseeable circumstances such as weather, flood or another similar situation. Initially, we have designed the system to work on three different road markers that consists of a right arrow, left arrow and straight arrow. This work will be enhanced further to include various different road markers in future phases of the project.

A vision system is the central part of this project as it enables the operator to capture images and various kind of image processing techniques are further applied before the final paint job by the robotic arm (robotic arm is not within the scope of the project).

The vision system consists of two parts; the image processing and data point calculation. After the Images are taken in real time with the help of a camera mounted in front of the vehicle, these captured images are processed using software to remove the background with the help of an image binarization technique [11] that is further used to calculate the data points.

2.1 Methods

Techniques used for this research project include, preprocessing of the images which includes fish eye removal, adjusting the orientation, contrast and brightness and data point extraction of the road markers. After the successful detection, the coordinates of images are calculated and passed to the robotic arm for the paint job. We will describe the image processing techniques in detail in chapter 3.

2.2 Existing methods

Two different kinds of techniques have been used in the analysis of pavement marking image recognition that can be distinctively categorized as recognition of road markers and recognition of lane markings.

The studies performed over the recognition of lane markings provide a great deal in terms of navigation application such as GPS widely used every day [12]. The image processing used for lane recognition has also opened the doors towards the development of Google's driver free cars [13], which employ complex array of cameras being used for that purpose. The automated recognition of the road markers involves image processing techniques along with artificial intelligence as used by [14-15]. These techniques have been used for various different purposes and have their own advantages.

However, none of the exiting methods incorporated the use of an automated robotic arm for the repainting of the existing road markers with a high accuracy in the recognition process. These techniques open new possibilities in transportation engineering with regard to maintenance, and help reduce costs as well as time for such jobs and provide a better way to serve the public in a timely fashion without causing significant traffic congestion at intersections.

Existing techniques for painting road markers used in the industry are limited to manual painting of the road markers as described in the introduction section of this thesis. However, using digital image processing to detect different road markers has been used in various research projects mainly focused on traffic safety.

Many of the studies for road marker detection consist of two steps; feature extraction and classification as described in [12]. In which, a multi-class support vector machine is used for classification purposes, whereas the inverse perspective images are used for extraction purpose. Template matching is used in both ways i.e. pixel based template approach [13] as well as the geometric pattern matching [14]. Grey level segmentation methods were presented in [15]. Candidate prototypes were encoded as arc spline to compare with the object candidates in [16]; this spline consists of extracted pixel list of the connected component as shown in the Figure 2.1. The left figure shows the extracted pixel list of the connected component. The black points on the right figure indicate the pixel list re-projected to the street plane. The red ones are the perpendicular points on the prototype [16-17].

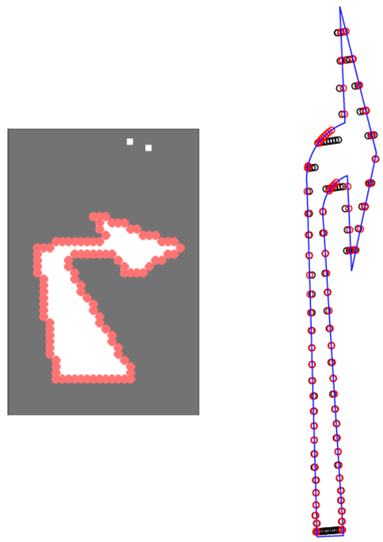


Figure 2.1: Extracted Pixel List of the Connected Component [16]

Various different research techniques are for the comparison among various different road markings extraction algorithms are described in [19]. Six representative road feature extractors and two variants were compared and based on these comparisons; the paper provides recommendations on what feature extractor to be used according to a certain application [20]. Furthermore, techniques such as inverse perspective mapping [22], which generates the top-view of the road, were also looked into for literature review. The positive-negative gradients extractors were used in for the geometric selection with respect to the feature width [23-26] were also studied for the literature review.

2.3 **Our Approach**

The proposed system consists of two parts; the image acquisition and the robotic arm for painting the road markers. The image acquisition is done with the help of camera mounted on the vehicle and then the images are processed to extract the information about the pavement markers such as the type, dimension, size and orientation of the pavement marker. Figure 2.2, shows a system diagram of the proposed system.

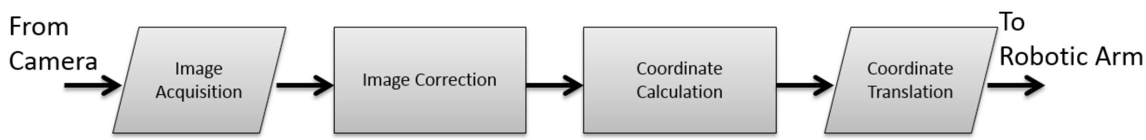


Figure 2.2: System Diagram of the Proposed System

The image acquisition equipment consists of a computer, camera, lenses, USB cables and the mounting parts. The image acquisition module is mounted in front of the truck equipped with the robotic arm and necessary paint supplies. After the images are captured using the camera and system which is triggered by the operator, image segmentation and feature extraction algorithms are applied that perform image processing techniques to extract the information and subsequently, the coordinates are calculated.

After the road markers are properly identified by the system, the coordinates of the particular road markers are calculated and passed on to the robotic arm for the paint job. The road marker identification and calculations of these parameters are based upon the standardized measurements as provided by the MN/Dot guidelines [8]. Furthermore, advance testing will be performed as the prototype is ready for testing purposes.

Chapter 3 : Vision Guidance System for the Robotic Roadway Message Painter

In this chapter, we will provide complete description of the system designed for the vision guidance system for the robotic roadway message painter. Preprocessing of the images and binarization will be discussed along with image artifact removal such as fisheye removal. We will also describe the equipment used such as camera and lens used to capture the images.

3.1 Proposed Method

Our approach is has significant impact on the methodology in which current road markers are being painted. The digital image processing part of the robotic arm painter will enable us to get the paint job done smoothly. We extract the features and these features are used for the edge detection, later on we perform computations for coordinates shown in Figure 3.1

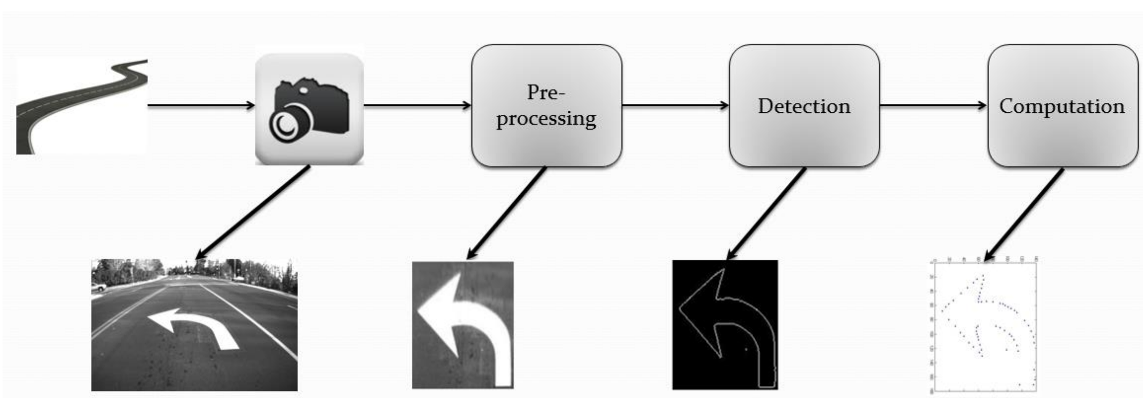


Figure 3.1: Vision Guidance System for the Robotic Roadway Painter

3.2 System Overview

A schematic of the image acquisition, processing, edge detection and computation is shown in the figure 3.2.

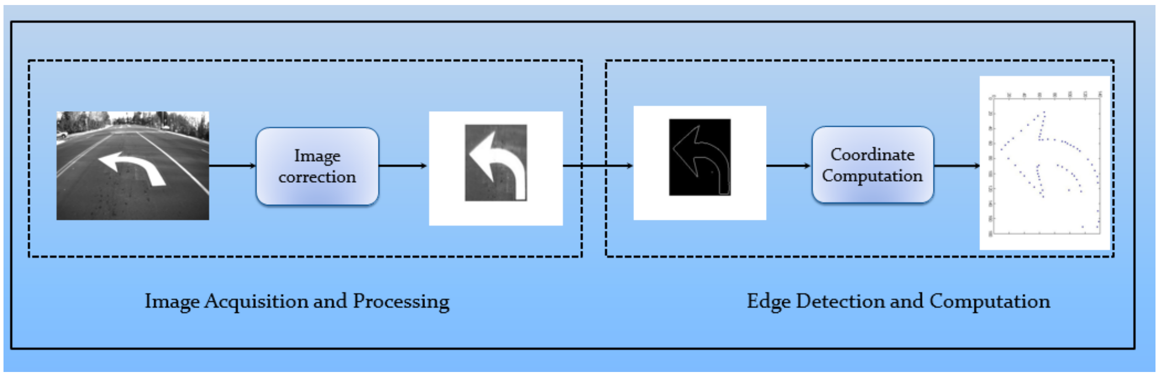


Figure 3.2: System diagram

Digital images were acquired using the camera mounted in front of the vehicle via an operator. The camera consists of a lens to capture larger area of the road view. Images are taken using the software and operator can crop the picture to get the road marker. Preprocessing of the images can be done in automated way or manually. In the preprocessing, images are processed to remove the fisheye effect. Once the image is cropped it is sent to the image binarization process. The image binarization process eliminates the background and a black and white image is retrieved.

3.3 Image Acquisition

Image acquisition is very important feature and the key is to acquire images that are clean and within the frame. Images are taken by the industrial scale camera mounted in the front of the truck. Images can be taken while vehicle is stopped by the operator and minor adjustments can be made such as zooming, cropping of the images, brightness etc. Images are stored in the memory of the laptop which operator is using to control the camera. It is necessary to mention that the capturing images should be taken from a certain distance so that they can be within the frame of the camera.

Mightex S-series USB camera is mounted in front of the paint truck to take the pictures using the software via USB cable [27]. The equipment used for taking the pictures is shown in the Figure 3.3. Images are loaded in the software as shown in the Figure 3.4.

Figure 3.3: Equipment used for Pictures [27]

Figure 3.4: Uploading Images in the Software

3.4 **Fisheye Removal**

The images taken using the mounted camera have fisheye lens distortions. These fisheye lens distortions can be one of two types: barrel distortion and pincushion distortion. Barrel distortion creates an image effect such a way that it looks as if it is wrapped around a barrel, while pincushion effect distorts the image towards the center of the image [29].

We applied the lens distort algorithm [29], to rectify the lens distortion in image. Figure 1 is an image taken for calibration purposes that shows a barrel distortion.

Figure 3.5: Fisheye effect on the Image

Various different parameters were applied to find the optimal correction value for the camera lens distortion. Distortion parameter was set to -0.28, border type is set to ‘fit’ and ftype which specifies the distortion model was set to 3. Figure 2 shows the corrected image after we apply the algorithm.

Figure 3.6: Fisheye Correction

3.5 **Image to World Coordinates**

We convert the captured image to world coordinates using the relationship between the intrinsic coordinates and the spatial locations for the rows and columns of the image to that of world coordinates. We sampled the image in planer world coordinate system, the intrinsic X and Y values align with the world X and Y coordinates [30].

3.6 **Cropping**

Image cropping is a technique used to crop the portion of the image after the fisheye removal and image to world coordinate conversion. We use the trapezoid tool to select the road marker within the axes by dragging it using the cursor. After the proper selection, the select area is cropped.

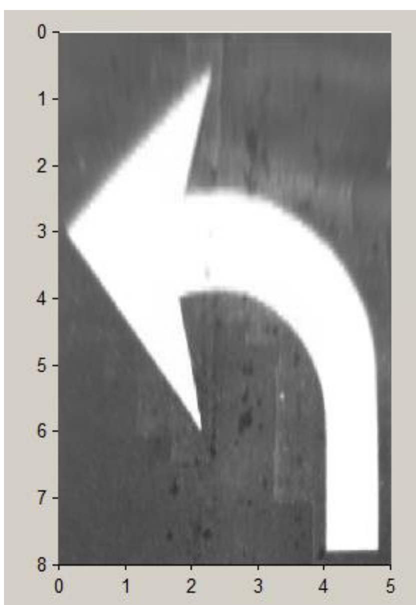


Figure 3.7: Cropping

3.7 **Binarization**

Once the image is acquired and cropped by the operator, the operator has the ability to apply the binarization tool to further extract the features from the image. The binarization process eliminates the surrounding background from the picture frame and the accurate picture of the road marker is retrieved in this process [11], as shown in Figure 3.8.

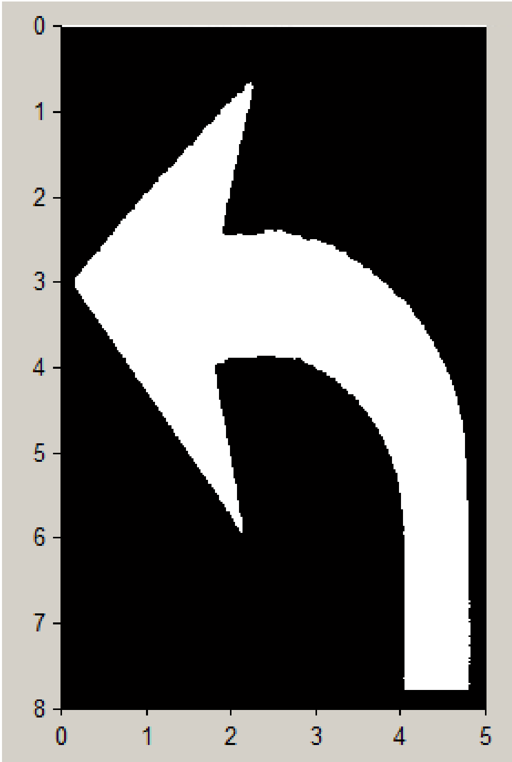


Figure 3.8: Binarization Process

Binarization helps the software to process the pictures in a way that is more understandable to the system for the processing purpose and detection is made easily afterwards. This is done by auto selecting the gray scale levels of the picture undergoing the binarization process. Various factors such as the time of day when the pictures are taken, weather or shadow of objects can cause erroneous results and selecting the best possible contrast is likely to generate better results.

3.8 Edge Detection

Edge detection is used for the detection of the edges; we used various different techniques to find the most robust edge detection method for our system.

Details of these edge detection methods and their merits are discussed in the results and analysis in Chapter 4.

3.9 Corner Detection

The detection of the road markers is done by two different ways. One is the automated detection by the system, and the other method is to do it manually for the roads with non-existing markers or the markers which are not easy to detect by the system as they can be in really bad shape or almost nonexistent for the operator to capture the image. In the first scenario, the operator get the pre-existing parameters or the size or orientation from the given database and send it to the robotic arm, in the latter case, image overlay techniques can be used and the subsequent parameters are fed to the robotic arm. The purpose of doing this is to make the job easy for the operator and the robotic arm in a way that the job can be done smoothly with less time and more accuracy.

Corner detection methods along with the computation of a 2D array of n by 2 size with x and y coordinates of the corner will be discussed in Chapter 4.

Chapter 4 : Results and Analysis

The system is designed in a way to capture images, detect the road markers and feed the parameters back to the robotic arm. The robotic arm then paints the road markers according to the specifications.

4.1 Results

Images are processed and the operator is given the freedom to change the images into the perspective view from where the coordinates are taken and translated and sent back to the robotic painter for the paint job.

Spatial transformation is applied using control point pairs. Spatial transformation returns a transformation structure T that can be further used to transform coordinates from one space. The transform is inferred from two n-by-2 arrays which contain the coordinates of n control points in the two 2D spaces. Transform coefficients are stored in a structure and interpretation of transform coefficients depends on the requested transform type [31]. In order to perform infer spatial transformation we have used moving points and fixed-point as the input matrices. Moving points matrix is a m-by-2, double matrix containing the x- and y-coordinates of control points in the image we want to transform, whereas the fixed-point matrix is a n-by-2, double matrix containing the x- and y-coordinates of control points in the base image. We also supplied the transformation type which specifies the type of spatial transformation to infer which in our case is ‘projective’.

We collected the fixed-point and stored in a 2 by 4 matrix using the center point select tool. The Control Point Selection Tool, a graphical user interface that enables us to select control points in two related images. The moving image is the image that needs to be warped to bring it into the coordinate system of the fixed image. Moving and fixed images can be either variables that contain grayscale, true color, or binary images, or strings that identify files containing these images [31]. We used MN DoT provide road marker template to collect the fixed control points as shown in the Figure 4.1.

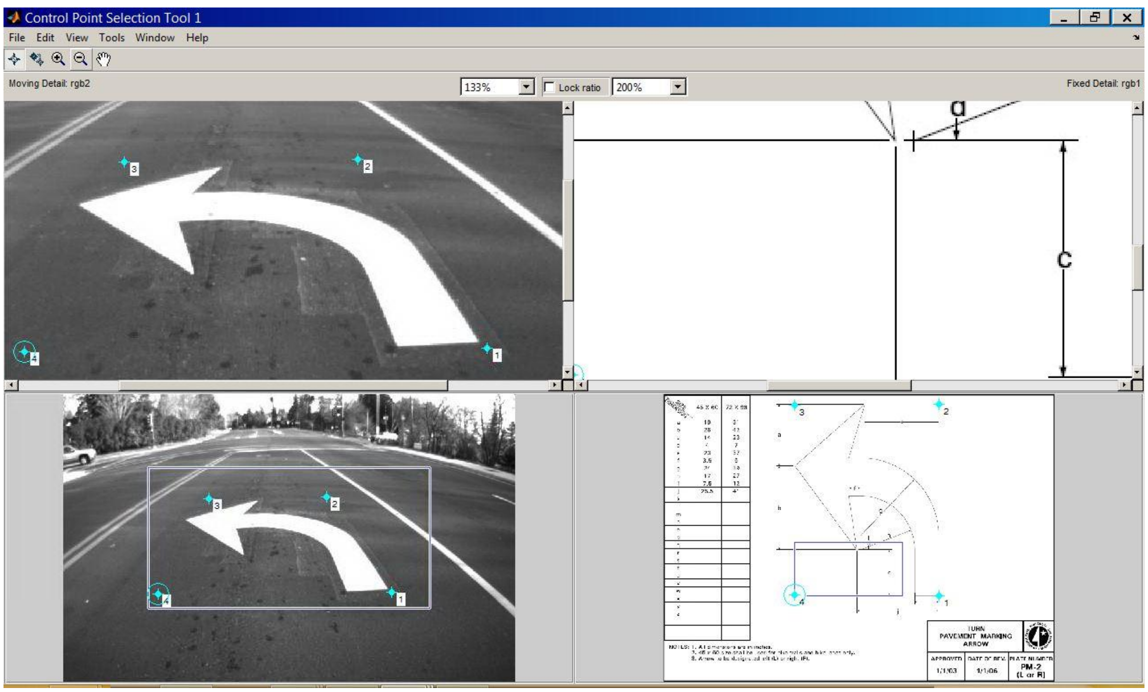


Figure 4.1: MovingPoint Selection

Figure 4.2, represents the moving points as the vertices of the trapezoid in blue line, for future reference we store the fixed points and moving points in the matrices and simply use them instead of selecting them every time.

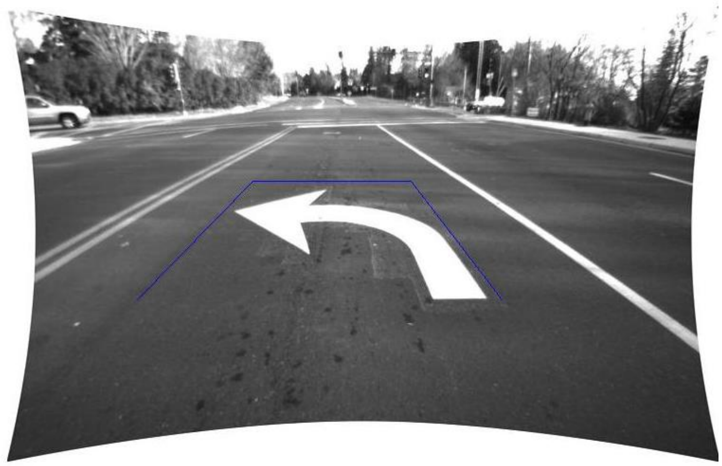


Figure 4.2: Fisheye Removal

After adjusting the camera position in such a way that the road marker fits in the trapezoid, we apply the image transformation based on the structure returned by spatial transformation to reflect the changes in the image processing. A 2-D spatial transformation to image is applied which transforms the image A according to the 2-D spatial transformation defined by T, resulting the Figure 4.3.

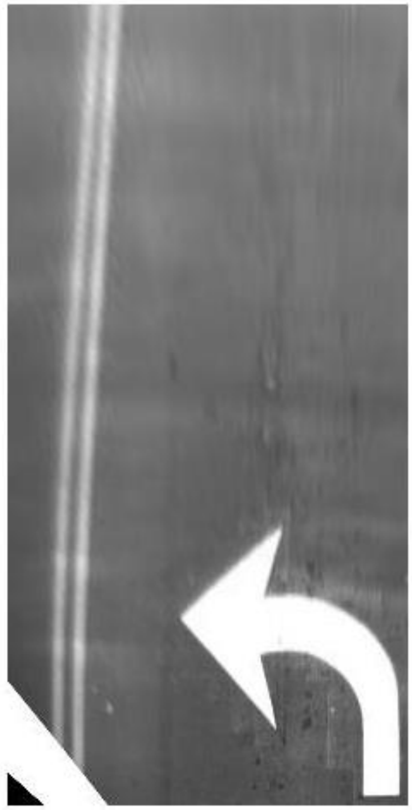


Figure 4.3: Spatial Transformation

We apply the image cropping tool and transforming the image in to world coordinates using image to world transformation. An image to world transformation object encapsulates world coordinates using the relationship between the intrinsic coordinates and the spatial locations for the rows and columns of the image to that of world coordinates. We sampled the image in planer world coordinate system, the intrinsic X and Y values align with the world X and Y coordinates [30].

The pixel spacing from row to row need not equal the pixel spacing from column to column. Figure 4.4, shows the resulting image.

Figure 4.4: Cropping Process

Edge detection is applied on the image using edge detection algorithm which takes an a binary image I as its input, and returns a binary image BW of the same size as I, with 1's where the function finds edges in I and 0's elsewhere as shown in Figure 4.5.

Figure 4.5: Edge Detection

Next step is to find the corner points in the image by using corner algorithm which in result returns the 2 by m matrix containing data points for that can be fed to the robotic arm for the painting purpose as shown in the Figure 4.6.

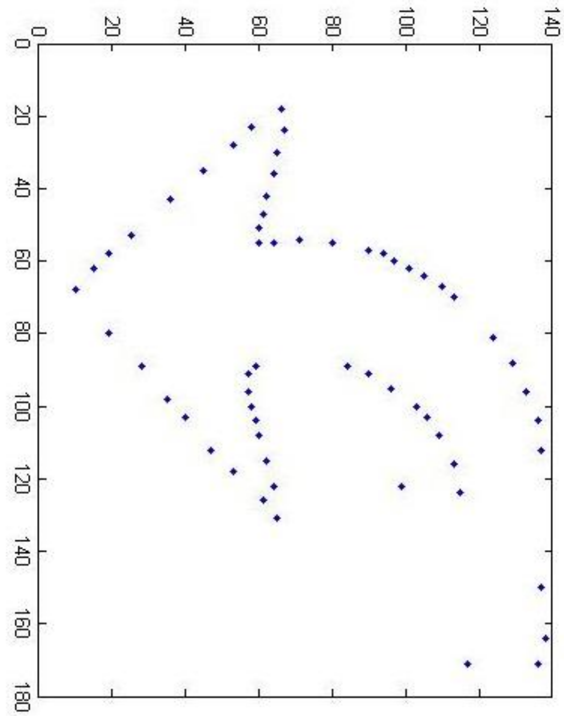


Figure 4.6: Corner Detection

4.2 **Edge Detection**

Unwanted areas or point can lead to erroneous results that can cause painting the road markers wrongly. In the edge detection, images are first converted into black and white images so that we can minimize the effect of background using binarization. Furthermore, we analyzed different edge detection methods and as an example, below is the image that was used for edge detection using three different scenarios.

At first we applied edge detection method (we used Roberts's method) without applying any threshold. Threshold is used to eliminate unwanted edges and unnecessary background noise from the image. Figure 4.7 and 4.8 shows the original and image after edge detection.

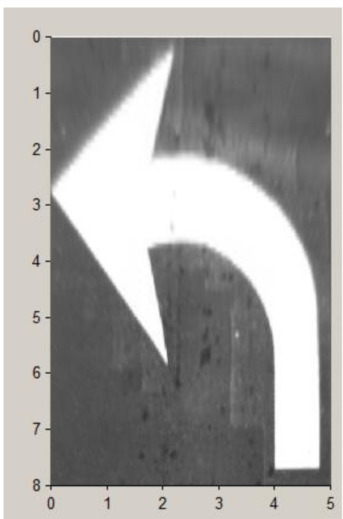


Figure 4.7: Original

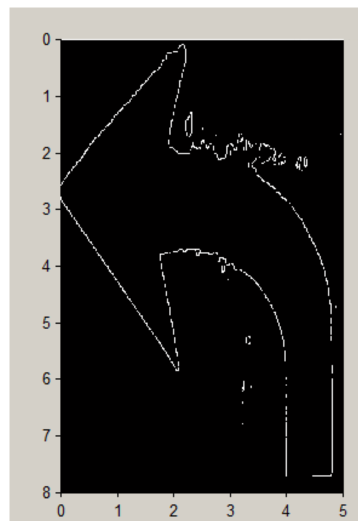


Figure 4.8: edge detection no threshold

Similarly, the same method is applied using the auto-threshold in which system determines the threshold level for the grayscale level of the image. We still found few unnecessary dots due to the fact that some unwanted areas were too strong Figure 4.9. To eliminate that, we applied adjustment to the auto threshold method and tweak the adjustment so we can get a crisp outcome as shown in the Figure 1.10.

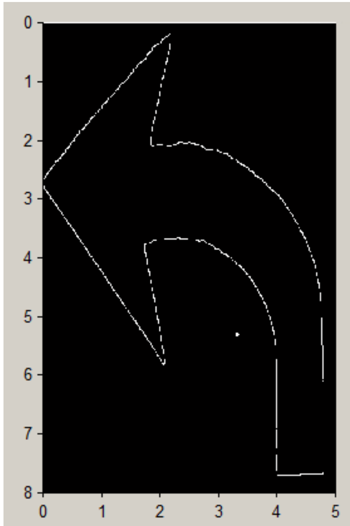


Figure 4.9: Auto threshold

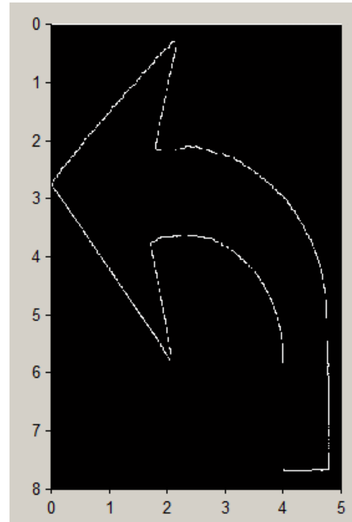


Figure 4.10: Auto threshold adjusted

We find that adjusting the threshold level can help us eliminate the unwanted background noise, which is detrimental in this experiment for the accuracy of the road marker painting. Furthermore, we applied the edge detection technique before and after applying the threshold.

Comparison of Different Methods before applying Threshold

Four different edge detection methods were used for the comparison; namely, Roberts, Sobel, Canny and Prewitt. We find out that most of these method work great with some minor background noises except for Canny which caused detection of unwanted background significantly. Figure 4.11-14 are the results from the experiment

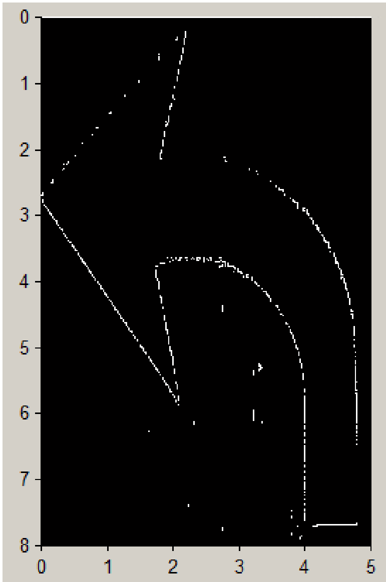


Figure 4.11: Roberts

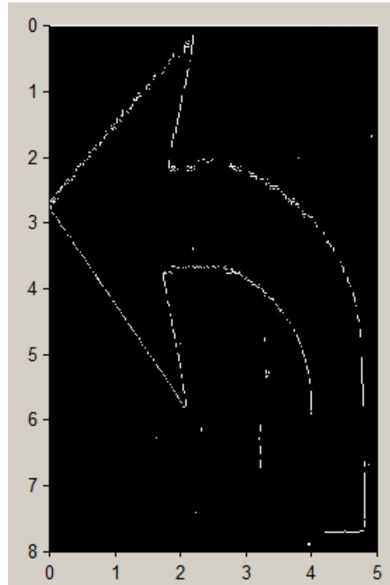


Figure 4.12: Sobel

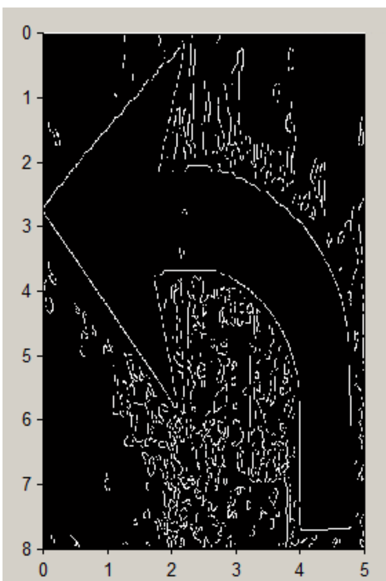


Figure 4.13: Canny

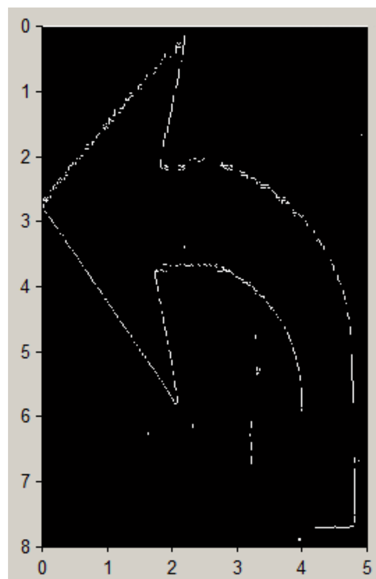


Figure 4.14: Prewitt

Comparison of Different Methods after applying Threshold

Much better and significantly improved results were obtained after applying the adjusted threshold first for each of these methods, Figure 4.15-18. There were not much significant visible difference in terms of image edge detection.

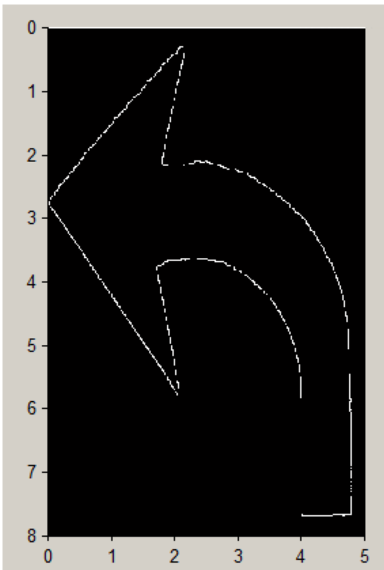


Figure 4.15: Roberts

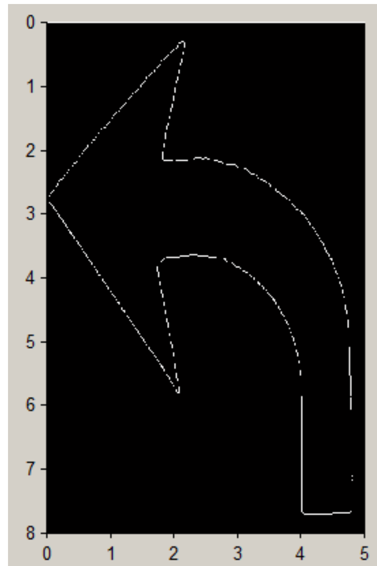


Figure 4.16: Sobel

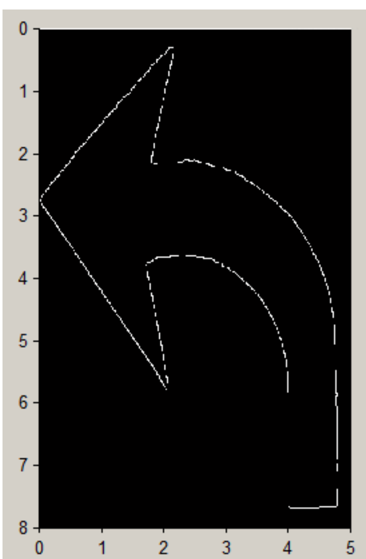


Figure 4.17: Canny

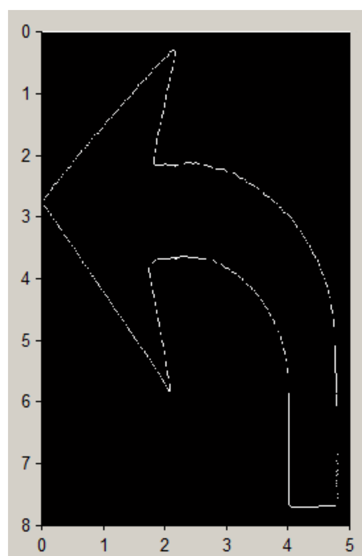


Figure 4.18: Prewitt

4.3 **Corner Detection**

The purpose of corner detection is to get the discrete points that can be fed to the robotic arm for the paint job. It is essentially an x by 2 array for points, where x and y coordinates of each point are stored. We used Minimum Eigen value method Figure 4.19 and Harris method 4.20 for corner detection using 'Prewitt' edge detection method. Neither of the methods demonstrate much difference in terms for corner detection. Below are the results for each method.

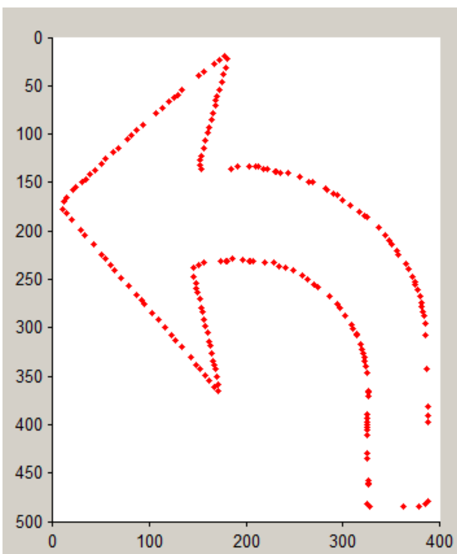


Figure 4.19: Minimum Eigen value

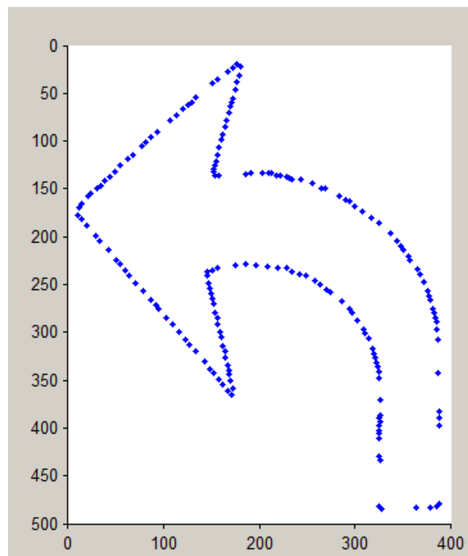


Figure 4.20: Harris Method

4.4 A Different Approach

Corner Metric approach

Corner metric matrix for the grayscale image is used to detect corner features and is the same size as the grayscale image. Larger values in the matrix correspond to pixels in the grayscale image with a higher likelihood of being a corner feature [32]. This approach provides us more flexibility and robustness over the edge detection as compared to previously used approaches in section 4.1. After applying the corner metric method and adjusting the image, we got the following results

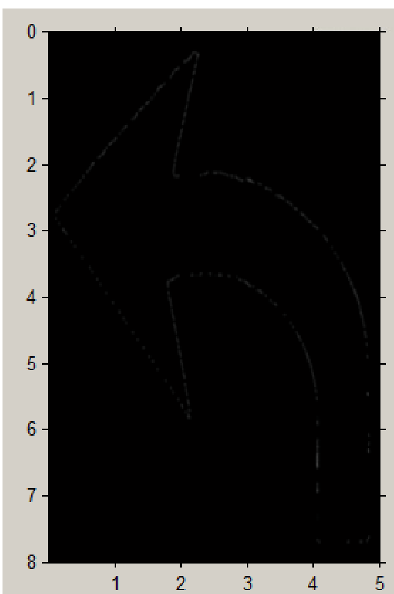


Figure 4.21: Corner Metric

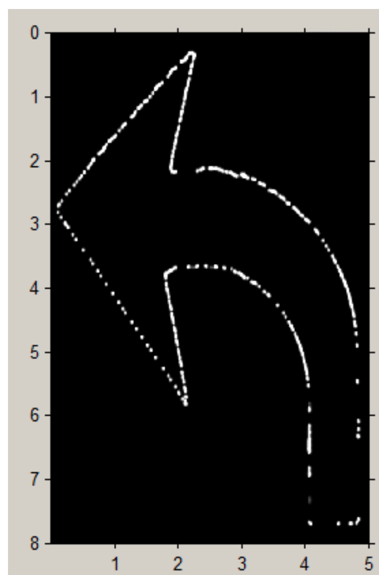


Figure 4.22: Corner Metric Adjusted

Figure 4.21 and 4.22 shows the results from the corner metric and the adjusted corner metric approach. We first apply the corner metric and then adjust is with the corner metric obtained in the first step.

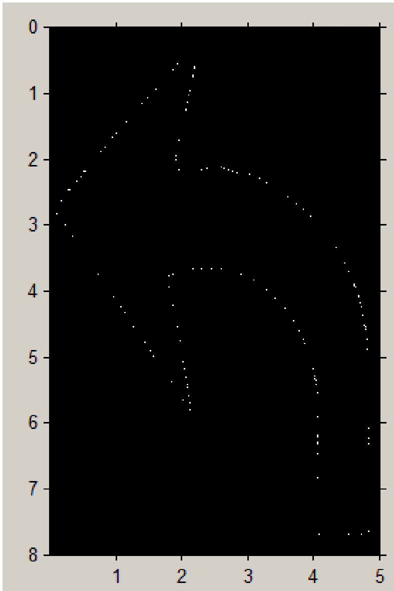


Figure 4.23: Regional Maxima

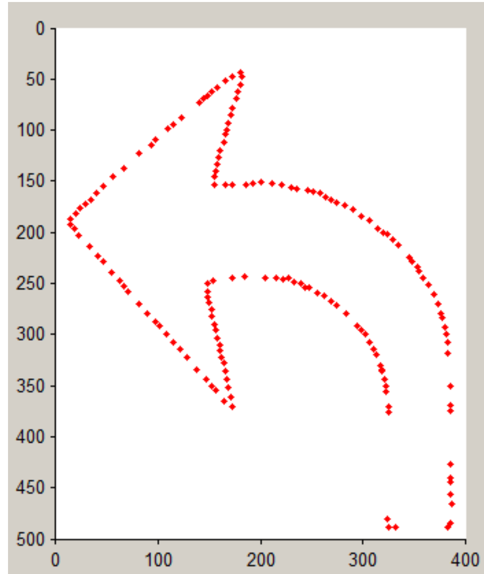


Figure 4.24: Corner Detection

We then find the regional maxima points on the adjusted corner metric image as shown in Figure 4.23. We simply use corner detection algorithm as in Figure 4.24.

By applying corner metric approach we eliminate the edge detection process as described in the previous method.

4.5 **Coordinate Computation**

The coordinate computation is performed after the detection process and the purpose is to feed the coordinated to the robotic arm. Coordinates are calculated from the given imagery during the corner detection process and since the image is already transformed to real world coordinate as per DOT standard road markers, thus providing an added benefit to make the paint job easier for the operator.

System has stored standard coordinates due to the fact each painted road marker has to comply with the DOT standards and only two different sizes are used for the that purpose; straight arrow has sizes 42×114 for roads and 26.5×72 for bike paths and bike trails as shown in the Figure 4.25. Our system transfer these stored coordinates to robotic arm based on the type of the arrow straight or curved and the size for road or bike path.

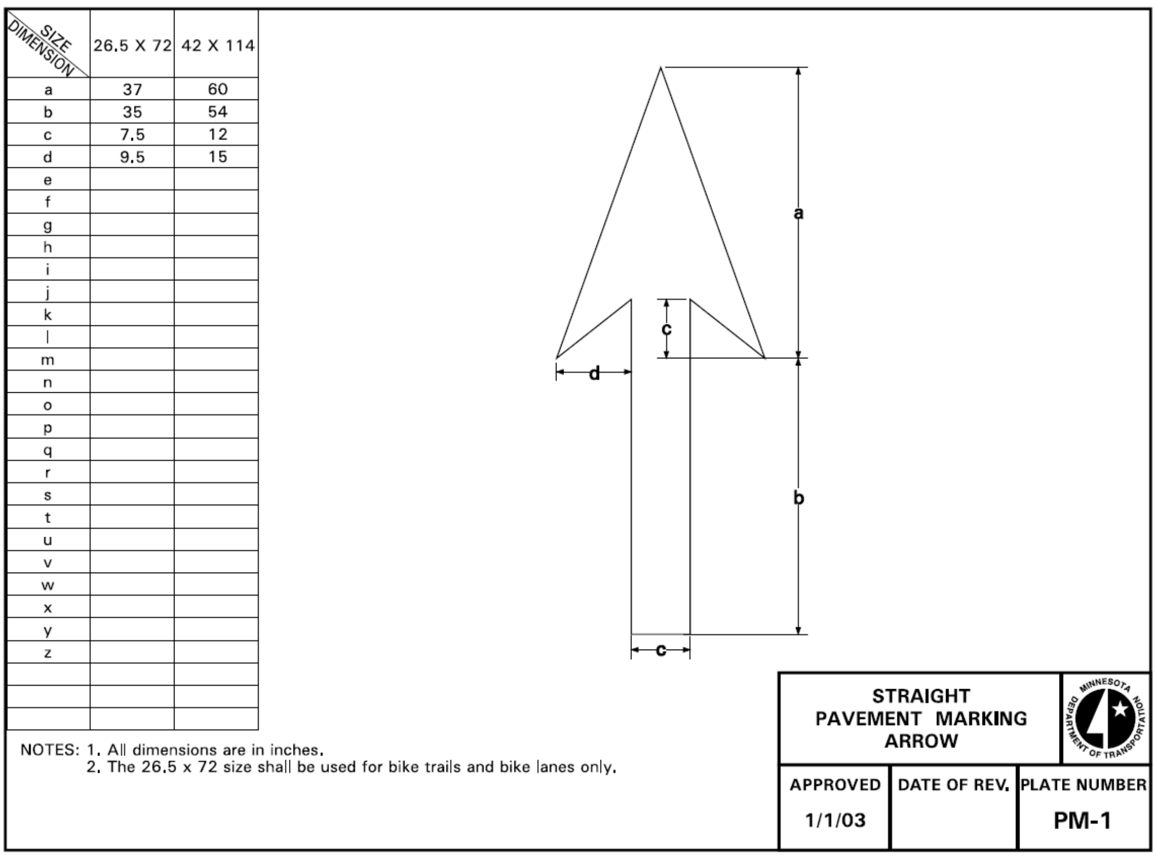
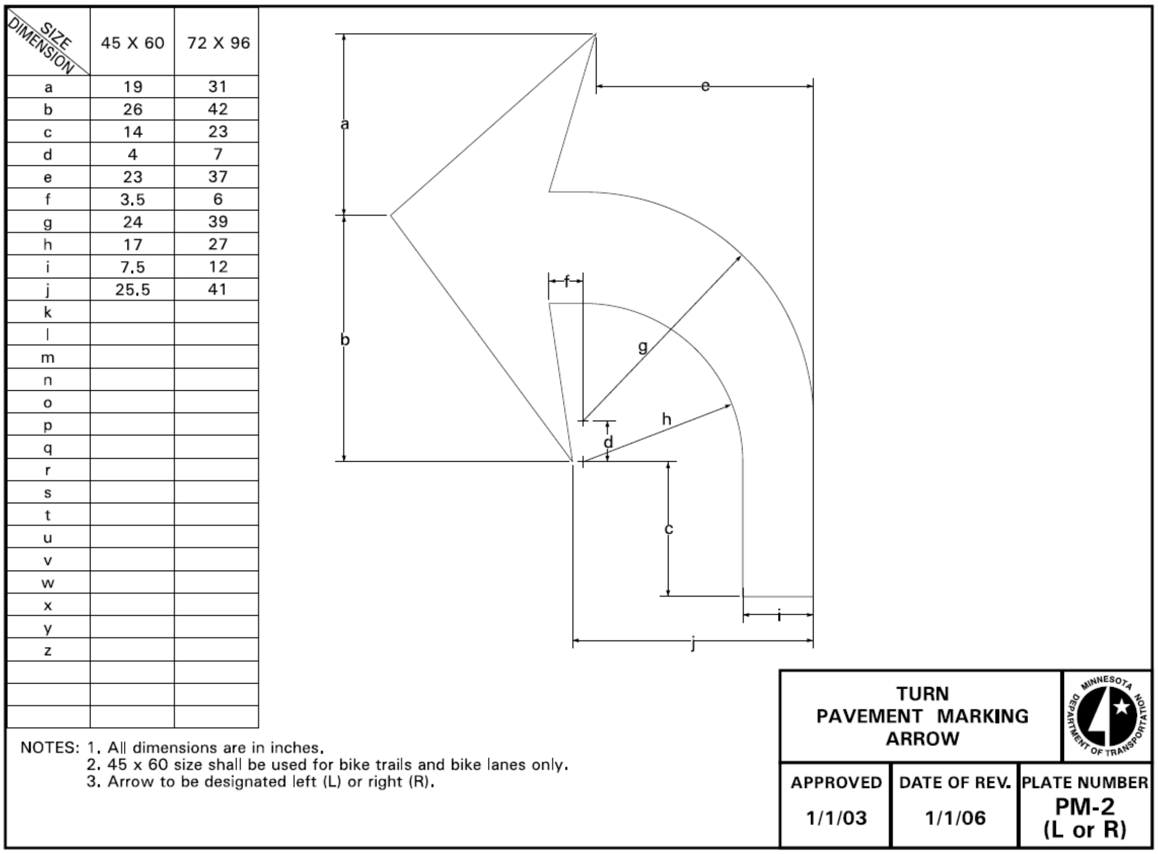


Figure 4.25: MNDoT Drawing Coordinates for Straight Arrow

Similarly, two different sizes are used for the curved arrow is used for the curved arrow and can be used as left or right arrow depending upon the shape. The parameter coordinates for curved arrow varies for the road and bike path i.e., 72×96 and 45×60 respectively as shown in the Figure 4.256.



DIMENSION \ SIZE	45 X 60	72 X 96
a	19	31
b	26	42
c	14	23
d	4	7
e	23	37
f	3.5	6
g	24	39
h	17	27
i	7.5	12
j	25.5	41
k		
l		
m		
n		
o		
p		
q		
r		
s		
t		
u		
v		
w		
x		
y		
z		

Figure 4.26: MNDoT Drawing with Coordinates for Curved Arrow

After these measurements are selected by the system based on the type of the road marker (straight, curved arrow) and the size of the marker (road, bike path) these parameters are passed on to the robotic arm for the paint job.

Chapter 5 : Conclusion

This chapter summarizes the results from the vision guidance system for the robotic roadway message painter and describes the future work.

5.1 Summary

Road markers were tested and analyzed using the system; imaging techniques were applied to improve the detection accuracy. Furthermore, the image coordinates were translated into the perspective coordinates for the robotic arm to do the appropriate paint job with more accuracy. Road makers were applied for the testing purpose with various different variations and promising results were obtained.

5.2 Future Work

We plan to advance this research by incorporating more road marker types and testing the system in a real time environment. We also plan to incorporate more rigorous image processing techniques to further improve the overall efficiency of the system in real time. Furthermore, we want to advance this research in a fashion that there is less burden on the operator and most of the work can be performed in a smooth automated way by the system itself.

Finally, the system robotic arm will be integrated with the software and will eventually lead to a safe, cost effective and time efficient method to repaint the road markers in an automated way.

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Appendix A

The size and dimensions of two arrows are shown in Figure A.1, as described by the FHWA "Standard Highway Signs and Markings" book

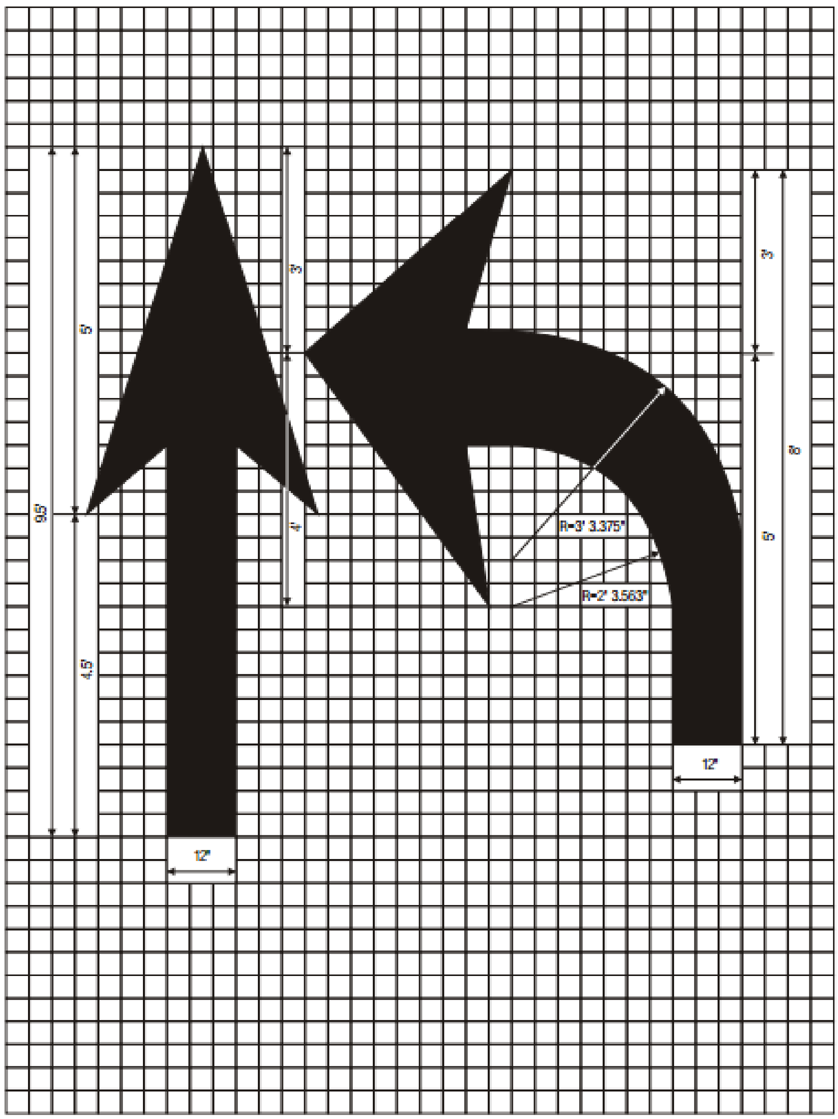

Figure 0.1: Size and Dimensions of Road markers

DIMENSION \ SIZE	26.5 X 72	42 X 114
a	37	60
b	35	54
c	7.5	12
d	9.5	15
e		
f		
g		
h		
i		
j		
k		
l		
m		
n		
o		
p		
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s		
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x		
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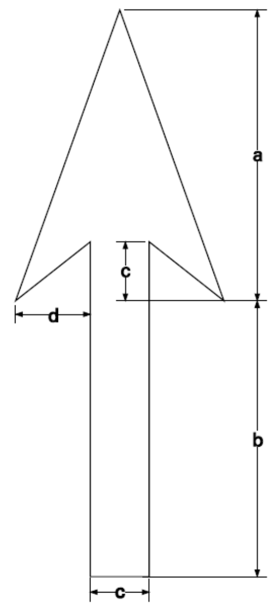
z		

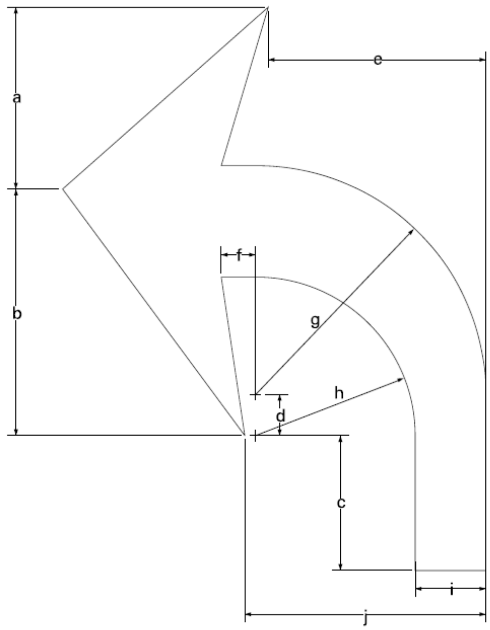


NOTES: 1. All dimensions are in inches.
2. The 26.5 x 72 size shall be used for bike trails and bike lanes only.

STRAIGHT PAVEMENT MARKING ARROW		
APPROVED	DATE OF REV.	PLATE NUMBER
1/1/03		PM-1

Figure 0.2: MNDoT Drawing Coordinates for Straight Arrow

SIZE / DIMENSION	45 X 60	72 X 96
a	19	31
b	26	42
c	14	23
d	4	7
e	23	37
f	3.5	6
g	24	39
h	17	27
i	7.5	12
j	25.5	41
k		
l		
m		
n		
o		
p		
q		
r		
s		
t		
u		
v		
w		
x		
y		
z		



NOTES: 1. All dimensions are in inches.
2. 45 x 60 size shall be used for bike trails and bike lanes only.
3. Arrow to be designated left (L) or right (R).

TURN
PAVEMENT MARKING
ARROW

MINNESOTA DEPARTMENT OF TRANSPORTATION

APPROVED	DATE OF REV.	PLATE NUMBER
1/1/03	1/1/06	PM-2 (L or R)

Figure 0.3: MNDoT Drawing Coordinates for Curved Arrow