A ROBUST TRAFFIC SIGN RECOGNITION SYSTEM

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ABSTRACT

A ROBUST TRAFFIC SIGN RECOGNITION SYSTEM

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The traffic sign detection and recognition system is an essential part of the driver warning and assistance systems. In this thesis, traffic sign recognition system is studied. We considered circular, triangular and square Turkish traffic signs. For detection stage, we have two different approaches. In first approach, we assume that the detected signs are available. In the second approach, the region of interest of the traffic sign image is given. Traffic sign is extracted from ROI by using a detection algorithm.

In recognition stage, the ring-partitioned method is implemented. In this method, the traffic sign is divided into rings and the normalized fuzzy histogram is used as an image descriptor. The histograms of these rings are compared with the reference histograms. Ring-partitions provide robustness to rotation because the rotation does not change the histogram of the ring. This is very critical for circle signs because rotation is hard to detect in circle signs. To overcome illumination problem, specified gray scale image is used.

To apply this method to triangle and square signs, the circumscribed circle of these shapes is extracted.

Ring partitioned method is tested for the case where the detected signs are available and the region of interests of the traffic sign is given. The data sets contain about 500 static and video captured images and the images in the data set are taken in daytime.

Keywords: Traffic Sign Recognition, Traffic Sign Detection, Ring-Partitioned Method, Specified Gray Scale Image, Histogram Specification

ÖZ

GÜRBÜZ TRAFİK İŞARETİ TANIMA SİSTEMİ

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Trafik işareti bulma ve tanıma sistemleri, sürücü uyarı ve yardım sistemlerinin önemli bir parçasıdır. Bu tezde trafik işareti tanıma sistemleri üzerine çalışılmıştır. Daire, üçgen ve kare trafik işaretleri dikkate alınmıştır. Algılama aşamasında, iki farklı yaklaşım tarzı vardır. İlk yaklaşımda, algılanmış trafik işaretinin mevcut olduğu varsayılmıştır. İkinci yaklaşımda ise trafik işareti görüntüsünün ilgilenilen kısmı verilmiştir. Böylece tanıma kısmının performansı algılama aşaması ile birlikte değerlendirilebilir.

Tanıma aşamasında, halkalara bölme yöntemi gerçekleştirilmiştir. Bu yöntemde, trafik işareti halkalara bölünür ve normalleştirilmiş bulanık histogram, görüntü açıklayıcı olarak kullanılmıştır. Halkaların histogramları, referans histogramlarla karşılaştırılır. Halkalara bölme, dönmeye karşı gürbüzlük sağlar, çünkü dönme işlemi halkaların histogramını etkilemez. Bu özellik daire işaretler için son derece önemlidir çünkü daire işaretlerde dönmeyi tespit etmek çok zordur. Aydınlanma problemini çözmek için belirlenmiş gri ölçekli görüntü kullanılır.

Bu yöntemi, üçgen ve kare işaretlere uygulamak için ilgili işaretlerin çevresel çemberi bulunur.

Halkalara ayırma yöntemi, bulunmuş işaretin ve trafik işareti görüntüsünün ilgilenilen kısmı verildiği durumlar için test edilmiştir. Data set 500 adet statik ve videodan alınmış görüntülerden oluşmuştur.

Anahtar Kelimeler: Trafik İşareti Algılama, Trafik İşareti Bulma, Halkalara Bölme Yöntemi, Gri Ölçekli Görüntü, Histogram Tanımlama

To My Parents

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LIST OF ABBREVIATIONS

ADAS: Advanced Driver Assistance Systems

CSS: Curvature Scale Space

CHT: Circular Hough Transform

HSV: Hue Saturation Value

RGB: Red Green Blue

ROI: Region of Interest

RHT: Randomized Hough Transform

TSR: Traffic Sign Recognition

SVM: Support Vector Machines

RHT: Randomized Hough transform

CHAPTER 1

INTRODUCTION

Traffic Sign Recognition (TSR) system is used to detect and recognize traffic signs from video sequences. TSRs have two applications: Advanced Driver Assistance Systems (ADAS) and mobile mapping.

An ADAS is used to improve driving comfort and traffic safety by assisting the driver. These systems use environment sensors like radar, laser, vision and ultrasonic sensors [1]. These systems increase the road safety and passenger safety. Some examples of these systems are [2]:

- Automatic parking
- Active Cruise Control
- Lane departure warning system
- Vehicular communication systems
- Traffic sign recognition
- Blind spot detection
- Driver drowsiness detection

In ADAS, the task of the TSR system is to inform the driver about the traffic signs on the road.

Many car manufacturers like BMW, Audi and Opel produce cars with TSR systems. However, these systems can only recognize speed limits. Volkswagen Phaeton, which will be introduced on 2011, can also detect overtaking restrictions signs.

The second application of TSR system is the mobile mapping system. Mobile mapping is a technique for compiling information from a mobile vehicle. Road sign types and positions can be obtained by using mobile mapping system with TSR [3], [4].

Colors and shapes of the traffic signs are determined by the government and is arranged to be easily perceived by the drivers [5]. In TSR algorithms, mostly the shape and color features of the traffic signs are used. The TSR systems have basically two stages: detection and recognition . In detection stage, the traffic sign is extracted from a traffic scene image. After the detection stage, the output of this stage is fed to recognition stage where this input sign is classified.

Some problems that may occur during the TSR process can be stated on follows:

- Traffic signs are outdoor objects so illumination of signs varies continuously during day [5].
- TSR systems can be effected by weather conditions [6].
- Traffic signs may be damaged
- Traffic sings may be partially occluded by other objects.
- The applied algorithm should be suitable for the real time implementation [5].

1.1 Scope of the Thesis

In this thesis, the recognition stage of TSR systems is studied. Detection algorithms are implemented to analyze the recognition algorithm performance. For testing, static and video captured images are used. These images are taken in daytime. Circular, triangular and informational square Turkish traffic signs are considered.

Images in RGB space are used as input data for both detection and recognition stages. In detection stage, the shape based methods are used for circular and triangular signs, and a color-based method is used for square signs. For detection stage, we have two different approaches. In the first approach, a human observer extracts the contour of the traffic sign from the given image. In the second approach, the contour of the traffic sign is automatically determined from a given region of interest by using a detection algorithm.

In recognition stage, histogram-based ring partitioned method is implemented and this method is extended to triangular and square signs. Algorithms applied are developed in MATLAB.

The performance of the method is tested by using a data set containing 500 traffic sign images. The performance of the ring-partitioned method is given by considering the two detection approaches as explained. For circular and triangular signs, the detection approach does not affect the performance of ring-partitioned method. However, for triangular signs, the performance of the ring-partitioned method is affected by detection approach. When the second approach is performed, the performance of the ring-partitioned method decreases with respect to the performance of first approach. In addition, the still images and video captured images are compared.

1.2 Organization of the Thesis

In Chapter 2, some of the methods, used for Traffic Sign Recognition Systems in previous researches, are mentioned.

Chapter 3 gives the details about ring-partitioned method in this thesis and the background information about this method.

Chapter 4 gives the experimental results.

Finally, Chapter 5 includes the conclusion and the future work.

CHAPTER 2

LITERATURE SURVEY

In this chapter, we present some methods for traffic sign detection and recognition. Although there are numerous methods for detection and recognition in the literature, some of them are mentioned in this chapter. Some of these methods deals with only detection and only recognition problems. However, in the literature, there are also some methods that handle both the detection and recognition problems together.

Colour based and shape based detection techniques are discussed in section 2.1. Mentioned techniques in recognition stage are template matching based, matching pursuit based, learning based, and shape information based methods. In 2.2.1-2.2.4, these techniques are explained in detail. In section 2.2, in addition to recognition only methods, these systems are also covered. Recognition stage is discussed in details by considering the scope of the thesis.

Colour based and shape based detection techniques are discussed in section 2.1. Mentioned techniques in recognition stage are template matching based, matching pursuit based, learning based, and shape information based methods. In 2.2.1-2.2.4, these techniques are explained in detail.

2.1 Detection

Fleyeh [7] proposes a traffic sign detection system based on colour segmentation. Fleyeh uses HSV colour space because Hue component of HSV is invariant to shadows and highlight. Saturation and value components of HSV are used to define the regions where hue component is meaningful. The output image is divided into 16x16 images and these images are used as seeds in region growing algorithm. If the numbers of white pixels are above a given threshold, region-growing algorithm is applied to that seed. The purpose is to find the object that is possibly a traffic sign.

Ghica et al. [8] propose a method based on vector distance in RGB space. They define a reference colour and a threshold. They compute distance of a given pixel to the reference colour. If the distance between the given pixel and the reference colour is below the threshold, the pixel is assigned to a new reference colour.
In RGB space, the pixel c is a linear combination of Red, Green and Blue colour component.

$$c = c1 * Red + c2 * Green + c3 * Blue \tag{2.1}$$

where $0<c1, c2, c3<1$

The distance between pixel c and a reference colour is computed by:

$$d = \sqrt{(r1 - c1)^2 + (r2 - c2)^2 + (r3 - c3)^2} \tag{2.2}$$

After the detection stage, they use morphological filters for noise reduction.

Shadeed et al. [9] propose a detection method which is based on YUV and HSV space. Firstly, RGB image is transformed into YUV colour space. In YUV space, the same colour with different luminance is obtained when Y component is changed when U and V remains unchanged. Histogram equalization is performed on Y component of YUV space. In this method, the effect of light conditions are eliminated. Three threshold values are defined for equalized Y component by using the average, lower and upper values of equalized Y component. After thresholding, YUV image is transformed into RGB colour space. For colour segmentation, YUV and HSV colour spaces are used. In HSV space, colour is described by H component. In YUV space, U is positive if the blue is greater than certain percentage of red and green, and V is positive if the red is greater than certain percentage of green and blue. the AND operation is used to combine these results.

Escelera et al. [10] use a shape detector for traffic sign detection. Shape detection is applied after colour thresholding. The colour thresholding uses the colour ratio between the intensity of the specified colour and the sum of intensity of RGB. Corners are obtained by the convolution of the image with a specified mask. For square, triangle and circle signs, different masks are defined. Circle signs have no corner so these types of signs are detected like square signs. To distinguish the circle and square signs, three of four corner points are selected and the circumference of these corner points is calculated. If points belong to a circumference, the sign is accepted as a circle otherwise it is accepted as a square. After convolution, the thresholding is applied to the result of the convolution; the values above the limits are accepted as corners of the traffic sign.

Hatzidimos [11] proposes a method based on geometrical characteristics of the traffic signs. Firstly, the ROI is extracted by using colour thresholding. After colour thresholding, thinning algorithms is applied to reduce the thickness of edges. The Hough transform is applied to each ROI to detect triangle signs. The angles between the lines are calculated and if these angles are between certain thresholds, the ROI is detected as triangle traffic sign. To detect circle signs, Randomized Hough transform (RHT) is used.

Garcia-Garrido et al. [12] use Hough Transform for detection of circular and triangular traffic signs. Canny edge detector is used to extract edge image. The dynamical threshold is used for canny algorithm. This threshold is determined by the histogram. Dynamical threshold provides robustness for illumination conditions. For triangular signs, straight lines are detected and intersecting of lines are found and the angles between them are checked. The start and end points of the lines cannot be determined by using HT but HT can be applied to whole image and the intersecting lines can be found. To detect circular signs, The Circular Hough Transform is used.

Ulay [13] uses colour and shape based method for traffic sign recognition. In detection, using colour properties, HSV and RGB colour spaces are used and edge information is used for shape based detection. Two different methods have been used in order to combine these two features. First method uses per-pixel conjunction of colour and shape detection results to form search domain for shape detection algorithms. However, the second one uses per-pixel multiplication of these results in order to form the search domain. Each algorithm is tested and compared with the others by using both static images from different sources and video streams.

Özkan [14] presents a traffic sign detection system on FPGA hardware platform. Images on YUV space is transformed into RGB space. Colour segmentation algorithm is performed and the possible sign region can be determined. After colour thresholding, Sobel algorithm is applied and the edges of traffic signs can be extracted. After that, radial symmetry feature of traffics sign is used to detect circular traffic signs. Each algorithm is tested by using video and static images on FPGA platform.

Some other studies on traffic sign detection can be seen on [15], [16], [17], [18], [19], [20], [21]

2.2 Recognition

2.2.1 Template Matching Based Methods

In template matching, instances of possible images are stored in a database and these images are called template. The purpose of template matching is to find the best matched template with the input image [22].

Cyganek has proposed a template matching technique based on log polar transformation. This study contains both detection and classification stage of the Traffic Sign Recognition problem [23].

The log polar transform [24] can be described as:

$$r = log_B(\sqrt{(x1-c1)^2 + (x2-x2)^2}) \quad (2.3)$$

$$\propto = \tan^{-1}\frac{(x2-c2)}{(x1-c1)}, \; for\; x1 \neq c2 \quad (2.4)$$

Where (c1,c2) is the centre of transformation and B is the base of logarithm.

In this method, two classifiers at different scales are used. The classifier at coarse level is for detection stage and the aim of this stage is to detect the region that possibly contains the traffic signs. The classifier at fine level is for classification stage. To obtain different scale image, Gaussian pyramid is used. The Gaussian pyramid is explained in [25].

To provide robustness to rotation, the search space is extended to 2h and the logarithmic expression in log-polar transform provides robustness for different scales.

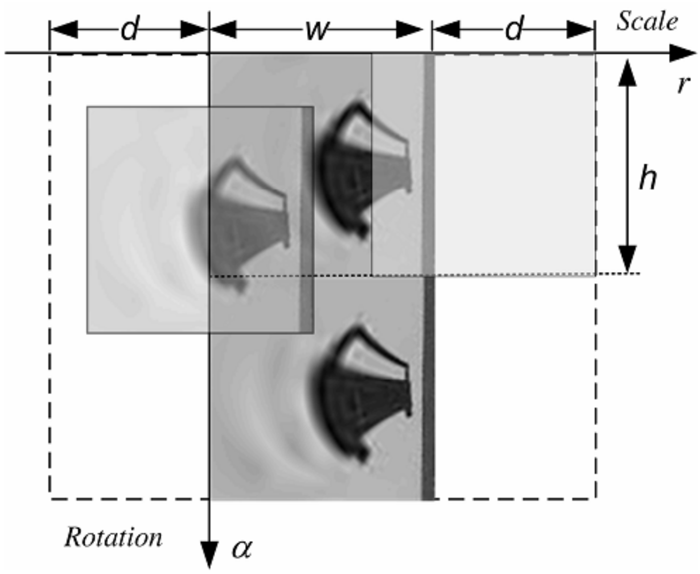


Figure 2.1 : Search Space

Matching measure used in this method is the cross-correlation. The cross correlation compensate the luminance variations in the traffic scene image.

The matching measure and template matching process have a high computational load. In (2), the method is implemented for 10 different circular traffic signs. The performance of the method is nearly % 98 but single run of the algorithm takes approximately 100 s.

Andrey and Jo [26] have developed a template matching technique based on shape analysis. In this technique, two groups of traffic signs are used. First group contains of “red bordered” signs and second group consists of information signs. For these groups, different recognition algorithms are used.

It uses a color and shaped based detection algorithm. In detection stage, firstly the candidate traffic signs are determined by using color properties. After that, the shape properties is used to eliminate the candidates that cannot be sign.

First group signs use the inner part of traffic sign for recognition. Each candidate of first group is classified as a circle or a triangle. Background shape histograms are used to determine candidate shapes.

For recognition step, the black region of the sign has to be analyzed. In the sign candidate, the black part of the sign is extracted and each candidate can be presented as a binary mask.

In template matching, the following template masks are used

$$T_{x,y}^{j} = \frac{N_{nonzero}}{8} \qquad (2.5)$$

where $N_{nonzero}$ is the number of nonzero neighbours of pixel at x,y.

Matching criterion is given as follows

$$matchID = arg\left[\min\left(\sum_j error1\left(T^j, C^i\right) + error2\left(T^j, C^i\right)\right)\right] \qquad (2.6)$$

where

$$error1(T^j, C^i) = \sum T^j - \sum T^j \cdot C^i \quad (2.7)$$

$$error2(T^j, C^i) = \sum C^i - \sum T^j \cdot C^i \quad (2.8)$$

Purpose of this step is to determine templates which match the candidate.

The technique is tested for 172 signs. The success rate of the method is about %90.

In [27], Malik et al. present a template matching technique based on pictogram classification. This technique just considers the signs with black inner part and circle signs with red borders.

Firstly, the input in RGB is transformed into HSC color space. Then the red colour segmentation is applied to this image. The red region that is segmented contains undesired red regions like red colored advertisements. To remove these undesired regions, filtering is applied. In filtering step, the area of each region is compared to a threshold value. After filtering step, shape detection is applied to remove undesired regions. In this step, the shape of the region is detected. If the shape of the region is triangle or circle, the region is assumed as a sign. Fuzzy Shape Descriptor is used in this technique.

After the sign is detected, the white region of the traffic sign is extracted. An AND operation is applied between the black region image and the extracted white region image. The result of this operation is the extracted pictogram image.

The extracted inner part is normalized. The matching does not performed in the entire database. The signs in the database are separated into two groups. The matching group is determined with respect to shape of the input traffic sign.

The recognition rate of the method is about 85%.

Havur [28] present a method based on template matching. This work also contains detection step of traffic sign recognition. The detection process is based on shape information. In template matching, normalized cross correlation is used to compute the distance between the input images and the reference image. Normalized cross correlation provides robustness to brightness. The method is tested with video frames taken in different time intervals of day.

2.2.2 Matching Pursuit Based Method

Huang and Hsu propose a traffic sign recognition technique based on matching pursuit (MP) method [35]. In this work, detection stage contains three stages. In the first stage, the possible road sign region is extracted from the input image by using by using the colour information of the traffic sign. In the second stage, Region of Interest (ROI) is searched for triangle and circular shapes. In the third stage, template-matching is applied to detect the traffic signs.

In the recognition stage, the Matching Pursuit is used. Matching pursuit (MP) decompose any signal into a linear expansion of waveforms that are selected from a redundant dictionary of functions.

In this work, about 450 traffic sign images are used for testing. The performance of the method is 94% for triangular signs and 91% for circular signs.

2.2.3 Learning Based Methods

Support Vector Machines (SVM) is a supervised learning technique that is used for regression and classification [29]. The data can be described as two sets of vectors in n-dimensional space. The aim of SVM is to find a separating hyperplane in n-dimensional space that maximizes the margin between the two data sets.

Consider two classes and the class label for these classes are (-1) and (+1). These two classes are linearly separable. The data X can be represented as X ={x^t,r^t} where r^t=+1 if x^t lies on first class and r^t=-1 if x^t lies on second class.

These two classes can be represented as:

$$w^t x^t + w_o \geq +1 \quad for\, r^t = +1 \tag{2.9}$$

$$w^t x^t + w_o \leq -1 \quad for\, r^t = -1 \tag{2.10}$$

Eq(2.9) and Eq(2.10) can be written as

$$r^t(w^t x^t + w_o) \geq 1 \tag{2.11}$$

The distance of x^t to the discriminant is given as

$$\frac{r^t(w^t x^t + w_o)}{||w||} \geq \rho \tag{2.12}$$

We want to maximize ρ but there are infinite solutions. We fix ρ$||w||$ = 1 and to maximize the margin, we minimize $||w||$. The optimizatiom problem can be defined as

$$min \frac{1}{2}||w||^2 \; subject\ to \;\; r^t(w^t x^t + w_o) \geq 1 \tag{2.13}$$

Eq. (2.13) can be solved by using Lagrange multipliers. The separating hyperplane can be defined as:

$$f(x) = \mathrm{sgn}(\sum_{i \Im SVs} \alpha_i K(x_i, x_j)) \tag{2.14}$$

Where K is a kernel function. If the problem is non-linear, the problem is transformed into a new space by using kernel function and a linear model is used in the new space.

In [30], Shi et al. propose SVM based on shaped based recognition model. In this work, four SVM kernels are compared and two different types of SVM are used. In this paper, two different feature selection techniques are used, direct binary representation and Zernike moments.

In direct binary representation, each image is resized to 36x36 pixels size and this image can be represented 1296 input vector. Each element of the vector is 0 or 1.

Zernike moments are computer vision techniques, which provide rotation invariance [31].

In SVM analysis, the optimal hyperplane can not be determined exactly so different SVM types are used. In [30], C-SVM and S-SVM is used. This type of SVM types are explained in [32].

A database which consisted of 600 traffic sign images, is used for training and testing. There are 50 images for each data set. The samples of each sign are divided into 2 categories, 30 for training and 20 for testing. The performance of SVM with binary classification is nearly 100% and the performance of SVM with Zernike Moments is above 95%.

Li et al. present SVM technique based on Tchebichef Moments [33]. They use four kernels and two different types of SVM like [30]. They divide the traffic signs into four different groups by using signs color properties. These classes are shown in Figure 2.2.

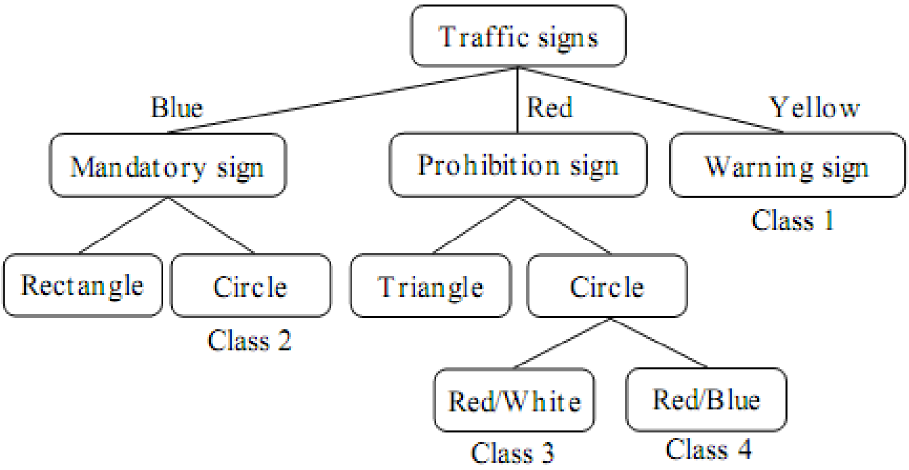


Figure 2.2 : The class diagram for [17]

A database which consisted of 3000 traffic sign image is used for training and testing. The performance of [30] is 95%, 98%, 92% and 99% for class 1-4, respectively.

Ishida et al. [34] propose a learning based method for degraded traffic sign images. In learning based methods, degraded images must be taken into consideration when forming a training data set. However, it is hard to collect such a data set containing all possible degradation conditions. This method generates a degraded traffic sign image by using original image. To generate degraded image from original image, three different degradation models are used for rotation, blur and segmentation. The parameters of the generation models are estimated from actual images. For recognition, the subspace method is used. The subspace method recognizes given images by comparing the similarities to subspaces. Using multiple frames in subspace method improves recognition accuracy. In this paper, ten consecutive frames for each sign are used.

The average recognition rate of the proposed method is 98.2%.

2.2.4 Shape Information Based Methods

J.T Ho et al. [36] propose a method for segmenting and recognizing traffic signs based on shape information. The segmentation stage is based on color ratio and symmetric properties of the traffic sign shape. The recognition stage uses the shape information. These shape information are moment, edge correlogram and concentric circular pattern.

In segmentation stage, HSI color space is used. A binary image is obtained by using a color ratio. Traffic sign regions are segmented based on the region size, and the symmetric properties in X- and Y-axes directions.

In the segmentation stage, three different shape information is used. These features are concentric circular pattern edge correlogram and moment.

The moment is given as Eq. (2.7) and the normalized moment η_{pq} is given by Eq.(2.8).

$$u_{pq} = \sum_x \sum_y (x - x')^p (y - y')^q f(x, y) \tag{2.15}$$

$where\ x' = \frac{m_{10}}{m_{00}} \quad and\ y' = \frac{m_{01}}{m_{00}}$

$$\eta_{pq} = \frac{\mu_{pq}}{\mu_{00}^{\gamma}} \tag{2.16}$$

$where\ \gamma = \frac{p+q}{2} + 1 \qquad (p+1) = 2,3,4 \ldots$

This feature is robust to rotation, scaling and translation.

Correlogram was proposed by J. Hung [37]. In histogram based methods, the different images may have the same histogram because histogram has no spatial information . Correlogram have spatial information and color information.

In this method, correlogram based on edge in binary images is used to reduce the computational complexity and memory usage.

In Concentric Circular Pattern, the intersection of edges in binary image and circles with different radius are found. This feature provides rotation and scaling invariance. In Figure 2.3 Concentric Circular Pattern is shown.

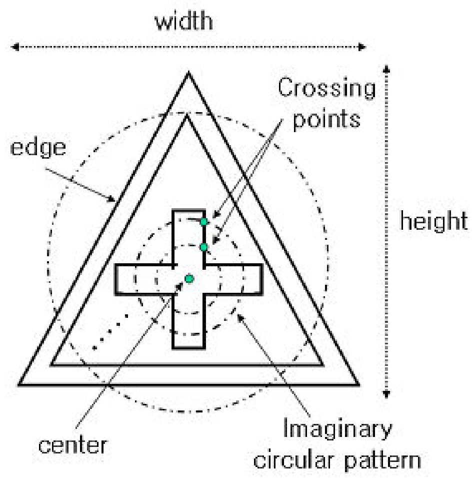


Figure 2.3 : Concentric Circular Pattern

Shape information values for each sign are stored in the database. These standard signs are compared with the detected signs. The weighted Euclidean distance is used for comparison. For each shape information, different weight is used.

The performance of the system is about 93% in 100 traffic signs.

Irmak [38] proposes a traffic sign recognition system on FPGA hardware platform. For triangle and rectangle signs detection, Hough transform is used. For circle signs detection, Modified Hough transform is applied to input image. After detection period, Region of Interest is extracted from input image. In recognition step, ROI is divided into regions and IPPs computed for each regions. IPPs can be described as the number of informative pixels and the sum of informative pixels for each region. After calculation, these values are compared with the IPPs of reference traffic sign images. This method provides scale invariance.

The algorithm is tested by using a data set containing well illuminated images and poorly illuminated images. The recognition success rate of the algorithm is 95% and 84% for well illuminated and poorly illuminated signs, respectively.

In the literature survey on recognition stage section , four different types of recognition methods are explained. Since each method uses a different data set, it is not possible to compare the performances of these methods fairly. For this reason, each method will be analyzed separately.

For template matching based methods, a sample of standard traffic signs are sufficient for reference. These methods can not handle with rotated traffic sign images. To deal with rotated circular traffic signs, Cyganek [23] and Malik [27] propose rotation invariant techniques. However, these techniques increase the computation time.

In learning based methods, a large data set must be collected for training stage. In SVM methods, Tchebichef Moments [33] and Zernike Moments [31] are used for feature detection. Zernike Moments are invariant to rotation and Tchebichef Moments are invariant to rotation, scaling, and translation. Ishida et al. [34] propose a generative learning based method. Generally, the training set must contain degraded version of the traffic sign images. The advantage of this method is that the degraded traffic sign images are generated from standard images. There is no need to collect degraded traffic sign images.

In shape based methods, the geometric features of the traffic signs are used. Unlike color features ,geometric features rarely change.

CHAPTER 3

THE RING PARTITIONED METHOD

In this chapter, the ring partitioned method and the background information for this method are introduced. In section 3.1, the background information is given. In section 3.2, the ring-partitioned method is introduced. In 3.3 – 3.5 the ring-partitioned method for circular, triangle and square signs are described.

The ring-partitioned method for traffic sign recognition is explained in [39]. The ring partitioned method is a histogram based method. The input image in the method is divided into ring-images. The histograms of these ring-images are calculated. This method does not need a lot of samples of traffic signs , only the standard traffic signs are used as reference images. As well the reference image is divided into ring-images like input image. The distance between the input image and all reference images in the database is calculating. The sign with the smallest distance is the output of the method.

The ring-partitioned method consists of three main stages. These stages are

- Specified Gray Scale Image
- Partitioning Stage
- Matching Stage

In Figure 3.1, the flowchart of the ring partitioned method is shown. The yellow part of the flowchart represents “Specified Gray Scale Image” stage of the method. The Blue part represents “Ring Partitioned Stage” and the red part represents “the Matching Stage”.

In real applications, the input of the method is an RGB image that is obtained from a video sequence. In such an application, the detection stage must be performed before the classification stage to extract the traffic signs from the RGB frame of the video sequence. So the ring partitioned method is implemented under the assumption that an RGB image has already been obtained. For this reason, the still images taken by camera are used in this thesis.

Some problems might occur during the traffic sign recognition process. The most possible problem is illumination difference between different traffic signs. To overcome this problem in ring partitioned method, , specified gray scale image is used instead of gray scale image.

Another problem in traffic sign recognition process is rotation of the traffic sign. In this method, the ring partitioned structure is used so the histogram is calculated for a ring part of the image. Even if the traffic sign is rotated, the histograms of these rings do not change.

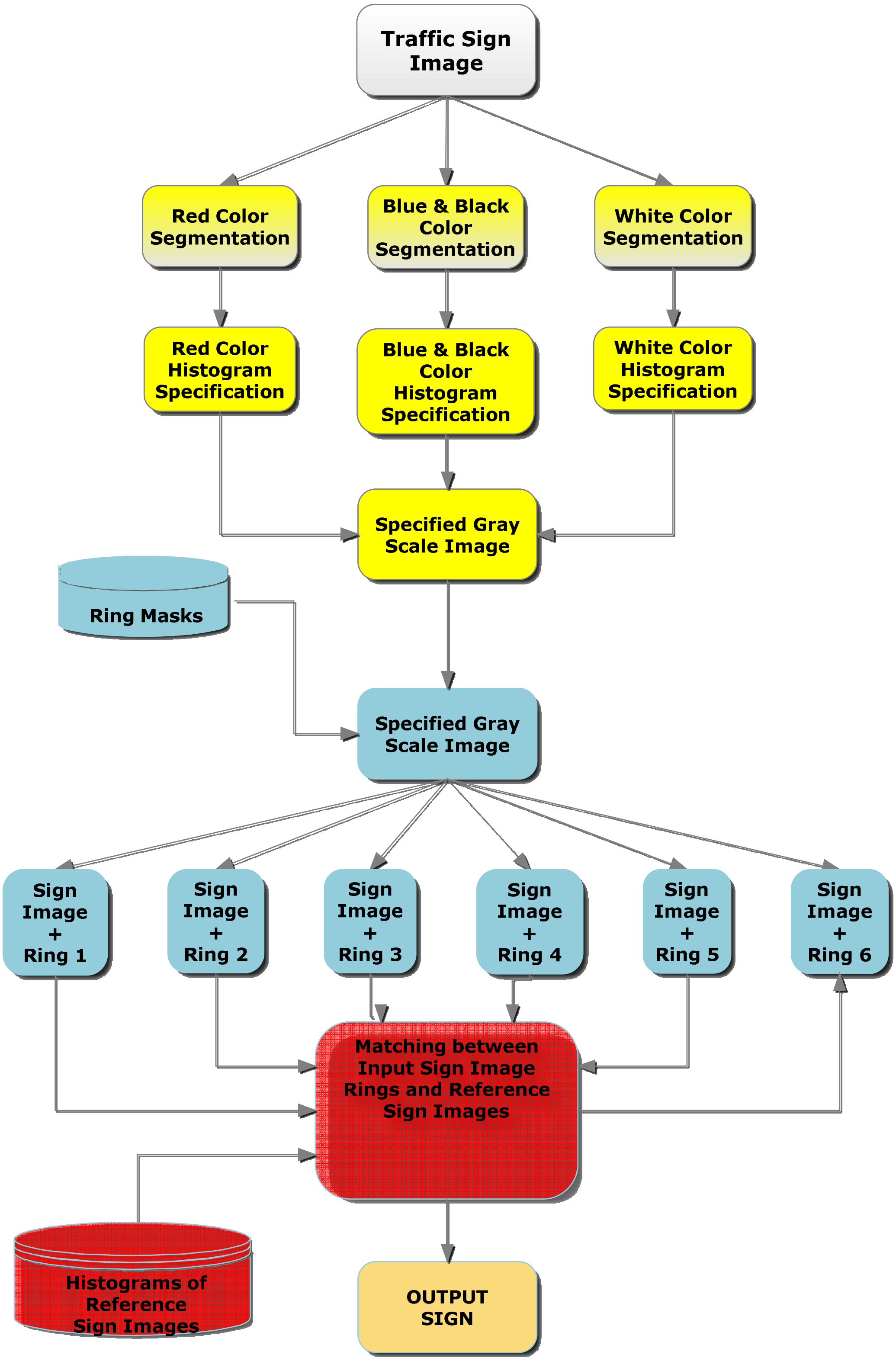


Figure 3.1 : Flow Chart of the Ring Partitioned Method

3.1 Background Information

In this section, the background information for ring-partitioned method will be introduced.

3.1.1 RGB Domain

In RGB domain, each color appears in its primary spectral components of red, green and blue. The RGB domain on a Cartesian coordinate system is shown in Figure 3.2 [40].

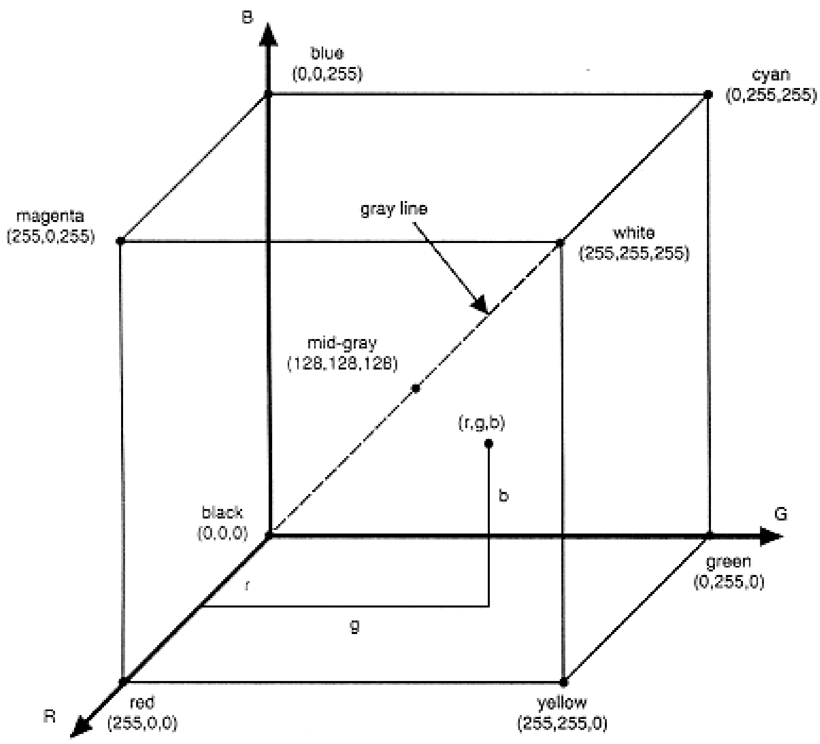


Figure 3.2 : RGB domain

The diagonal of the figure corresponds to the gray levels. In this diagonal, red, green and blue components are equal. The RGB color model is hardware oriented and is utilized in numerous image capturing, processing and rendering devices.

3.1.2 Color Segmentation

Color segmentation is a process that partitions an image into regions with the same color. Turkish traffic signs contain blue, black, red, white, yellow and green colors however in this thesis, only blue, black, red and white colors are considered. The color segmentation is performed for these colors. The color segmentation is performed in RGB domain.

Red color segmentation is defined [41] as

$$If\ (\ (R-G)>25\ and\ \ (R-B)>25) \tag{3.1}$$

Then assign pixel as red where R, G, B is the RGB components of the pixel respectively.

Similarly, Blue segmentation is defined as

$$If\ ((B-G)>25\ and\ (B-R)>25) \tag{3.2}$$

Then assign pixel as blue.

Black segmentation is defined as

$$If\ [\ (J<Th1)\ \ and\ ((R-Rc)^2+(B-Rc)^2+(G-Rc)^2\ \ )<Th2] \tag{3.3}$$

Then assigned pixel as black where R, G, B is the RGB components of the pixel and Th1 and Th2 are threshold values. In this thesis, Th1 = 120 and Th2=10000.

J is the gray scale value of pixel. The transformation RGB image is converted into grayscale values by using the following equation

$$J=0.2989*R+0.5870*G+0.1140*B \tag{3.4}$$

White color segmentation is defined as

$$If\ [\ (J > Th1)\ and\ ((R - Rc)^2 + (B - Rc)^2 + (G - Rc)^2\ ) < Th2] \tag{3.5}$$

Then assigned pixel as white where Th1 and Th2 are threshold values. In this thesis, Th1 = 100 and Th2=10000

3.1.3 Histogram Specification

Histogram specification is a technique that transforms the histogram of image into a specified histogram.

Histogram specification procedure is given in [40]

I. The histogram $p_r(r)$ of the given image is computed. $p_r(r)$ is defined as

$$p_r(r_j) = \frac{n_j}{MN} \tag{3.6}$$

Where r_j is the intensity level, n_j is the number of pixels in the j-th intensity level.

II. Use $p_r(r)$ to find the histogram equalization transformation by using

$$S_k = T(r_k) = (L-1)\sum_{j=0}^{k} p_r(r_j)$$
$$= \frac{(L-1)}{MN}\sum_{j=0}^{k} n_j \qquad k = 0, 1, 2, \dots, L-1 \tag{3.7}$$

where n_j is the number of pixels that have intensity value r_j and L is the total number of possible intensity levels in the image.
Round the resulting values, s_k, to the integer range [0, $L-1$].

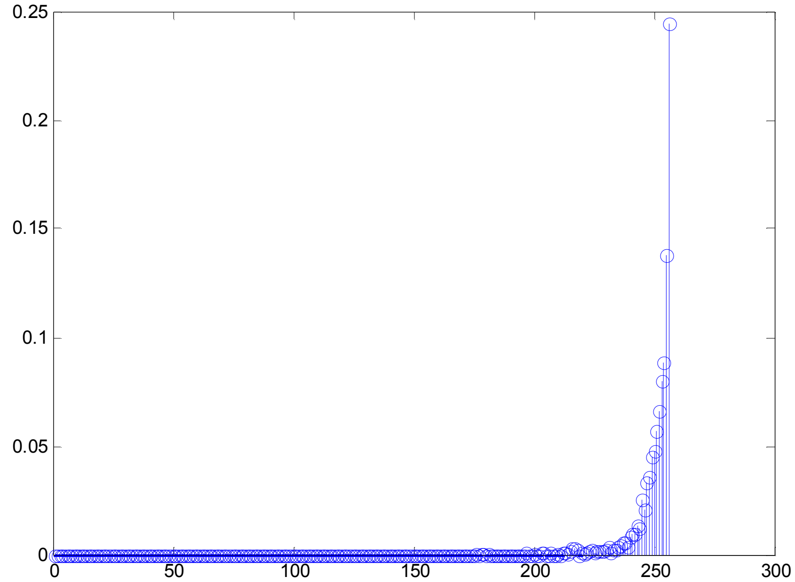
III. Compute all values of the transformation G using the Equation 3.8 for q = 0, 1, 2, …,$L-1$, where $p_z(z_i)$ are the values of the specified histogram. Round the values of G to the integers in the range [0,$L-1$]. Store the values of G in a table.

$$G(z_q) = (L-1)\sum_{i=0}^{q} p_z(z_i) \tag{3.8}$$

IV. For every value of s_k, k = 0, 1, 2, …,$L-1$, use the stored values of G from step 2 to find the corresponding value of z_q so that $G(z_q)$ is closest to s_k and store these mappings from s to z. When more than one value of z_q satisfies the given s_k (i.e. the mapping is not unique), choose the smallest value by convention.

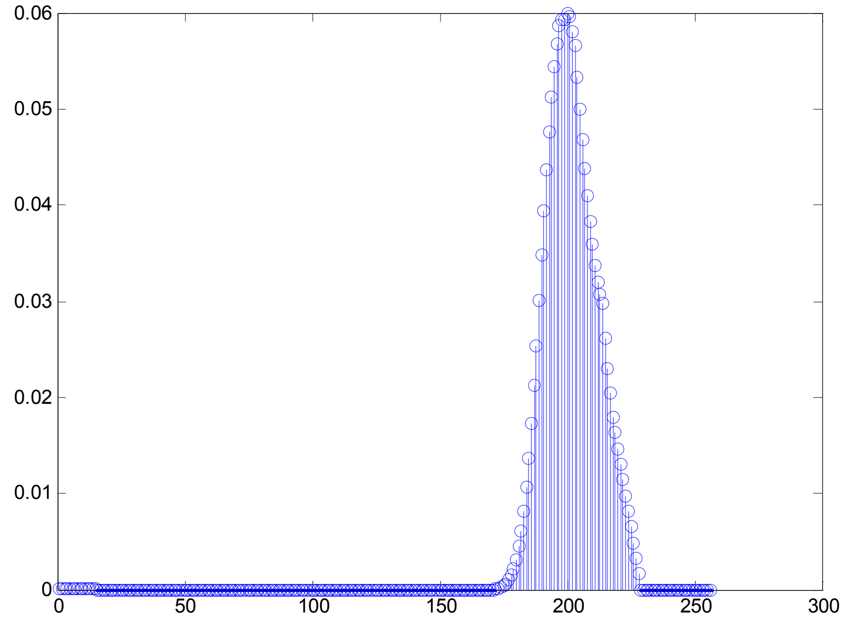
V. Form the histogram specified image by the first histogram equalizing the input image and then mapping every equalized pixel value, s_k, of this image to the corresponding value of z_q in the histogram specified image using the mapping found in step 3.

In Figure 3.3, the example of histogram specification procedure is given.

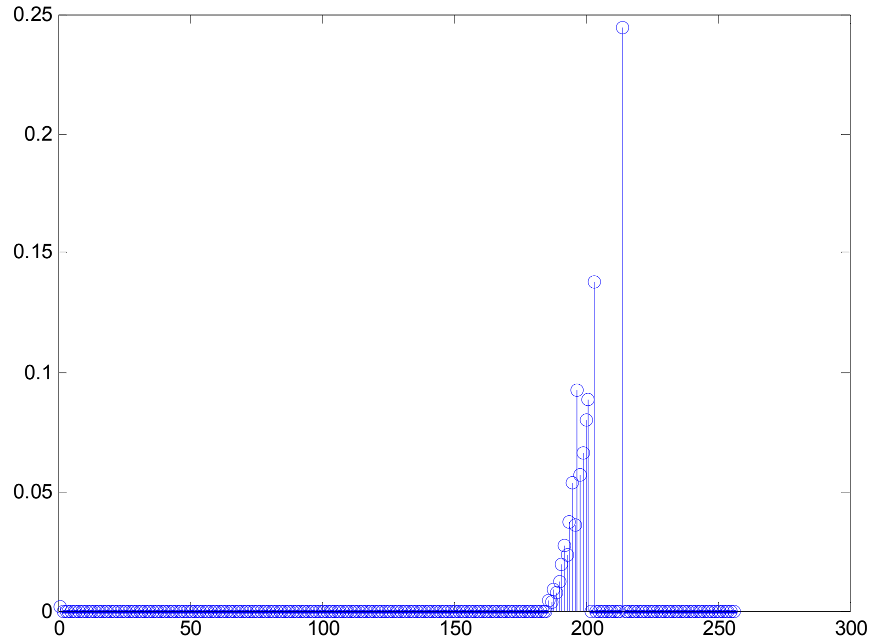


(a) The histogram of the original image

Figure 3.3 : Histogram Specification

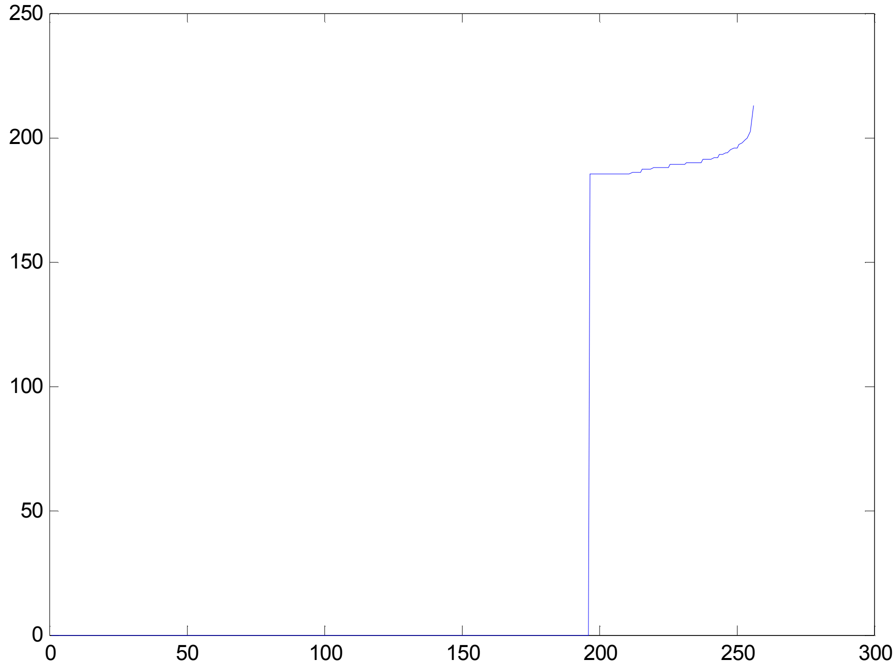


(b) Reference Histogram



(c) The output histogram of the histogram specification procedure

Figure 3.3 : Cont'd



(d) The transformation

Figure 3.3 Cont'd

Although the aim of the histogram specification is to transform the input histogram into reference histogram, the output of the histogram specification does not match exactly the reference histogram. This is due to fact that there is no exact inverse of the cumulative distribution function.

3.1.4 Circumscribed Circle

"In geometry, the circumscribed circle or circumcircle of a polygon is a circle, which passes through all the vertices of the polygon [42]". The center of this circle is called the circumcenter.

In this thesis, circumscribed circles of triangles are considered. The circumscribed circle and the corresponding triangle is shown in Figure 3.4

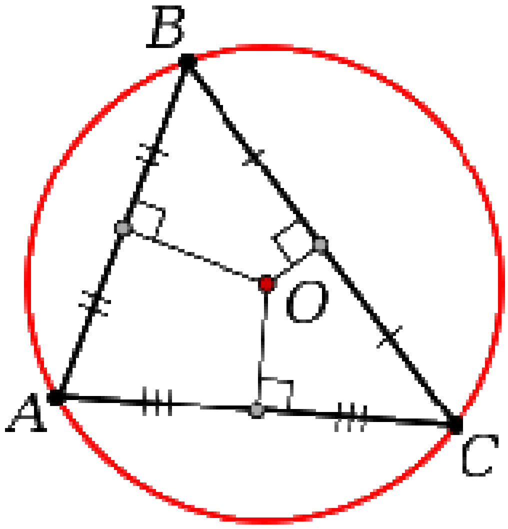


Figure 3.4 : The Circumscribed circle of Triangle

The type of triangle determines the position of circumscribed center :

- “If and only if a triangle is acute (all angles smaller than right angle), the circumcenter lies inside the triangle”

- “If and only if it is obtuse (has one angle greater than right angle), the circumcenter lies outside”

- “If and only if it is a right triangle, the circumcenter lies on one of its sides (namely, the hypotenuse). This is one form of Thales' theorem.”

The diameter of the circumcircle of the triangle can be computed by using Eq. 3.9.

$$\text{diameter} = \frac{\text{abc}}{2*\text{area}} = \frac{|\text{AB}||\text{BC}||\text{CA}|}{2*|\Delta\text{ABC}|} = \frac{\text{abc}}{2\sqrt{\text{s(s−a)(s−b)(s−c)}}}$$
$$= \frac{2\text{abc}}{\sqrt{(\text{a+b+c})(-\text{a+b+c})(\text{a−b+c})(\text{a+b−c})}} \quad (3.9)$$

where a, b, c are the lengths of the sides of the triangle and s is the semi perimeter.

A, B, C are the coordinates of the corner points of a triangle. The circumcircle is satisfying the following equations:

$$|v-u|^2 = r^2$$
$$|A-u|^2 = r^2$$
$$|B-u|^2 = r^2$$
$$|C-u|^2 = r^2 \quad (3.9)$$

By using Eq 3.8 , it is guaranteed that the distances between points A, B, C, v and the center of the circle are equal. These equations can be reduced to the matrix given in eq 3.11

$$\begin{vmatrix} |v^2| & -2v_x & -2v_y & -1 \\ |A^2| & -2A_x & -2A_y & -1 \\ |B^2| & -2B_x & -2A_y & -1 \\ |C^2| & -2C_x & -2A_y & -1 \end{vmatrix} \quad (3.10)$$

The circumscribed circle may be described as following way:

$$det \begin{vmatrix} |v^2| & -2v_x & -2v_y & -1 \\ |A^2| & -2A_x & -2A_y & -1 \\ |B^2| & -2B_x & -2A_y & -1 \\ |C^2| & -2C_x & -2A_y & -1 \end{vmatrix} = 0 \quad (3.11)$$

S_x and S_y , the center of the circumscribed circle, can be computed by using Eq (3.13) and Eq (3.14):

$$S_x = \frac{1}{2} det \begin{vmatrix} |A|^2 & A_y & 1 \\ |B|^2 & B_y & 1 \\ |C|^2 & C_y & 1 \end{vmatrix} \tag{3.12}$$

$$S_y = \frac{1}{2} det \begin{vmatrix} A_x & |A|^2 & 1 \\ B_x & |B|^2 & 1 \\ C_x & |C|^2 & 1 \end{vmatrix} \tag{3.13}$$

By using Eq. 3.9 , the diameter of the circumscribed circle can be computed. By using the circumcenter and diameter, the circumcircle of any triangle can be determined.

3.1.5 Fuzzy Histogram

Intensity levels of a digital image are in the range [0, L-1] . The histogram of digital image is a discrete function

$$h(r_k) = n_k \tag{3.14}$$

where r_k is the k-th intensity value and n_k is the number of pixels in the image with intensity r_k.
The histogram is normalized by dividing each of its components by the total number of pixels in the image.

Fuzzy sets are characterized by a membership functions which varies in the range [0 1]. Fuzzy numbers are the convex sets on a real line and have been investigated in detail in [43].

In Figure 3.5, an example of a fuzzy set is given

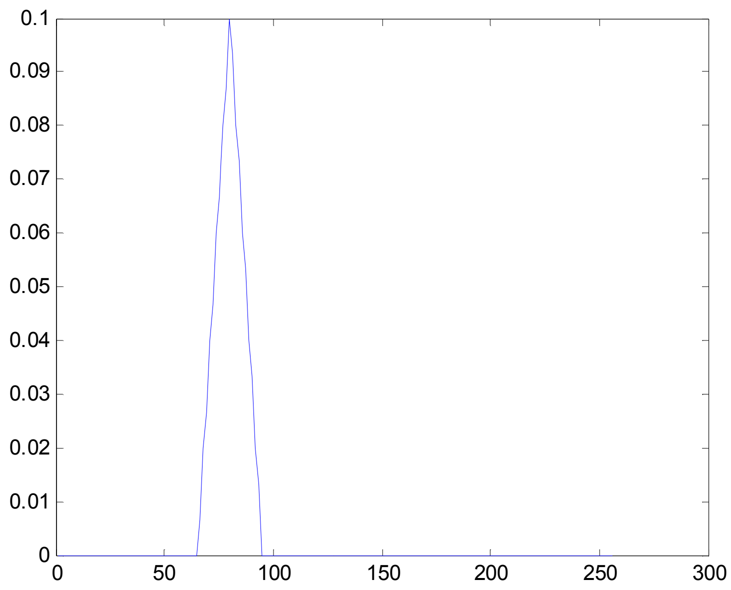


Figure 3.5 : Example of Membership distribution of a Fuzzy Set

The gray value n in a digital image can be (n+1) or (n-1) without any appreciable change in the visual perception. Such impressions are not considered in classical representation schemes. By considering gray values as a fuzzy numbers, we incorporate the uncertainty arising out of the impression of gray levels into the mathematical framework of image processing [44].

The fuzzy histogram can be explained as

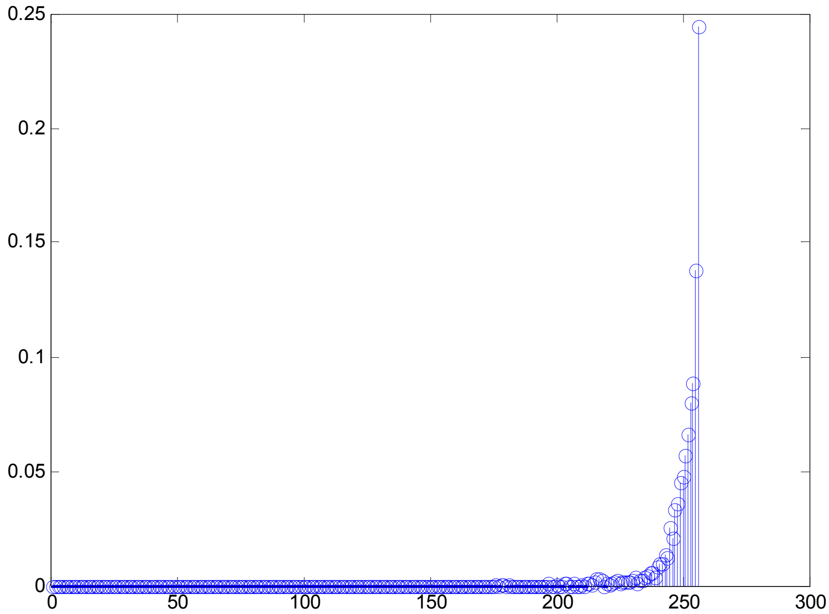
$$h(c) = \sum h(c')\mu_c(c') \qquad (3.15)$$

where μ the fuzzy membership function and h(c') is the classical histogram

This fuzzy histogram operation can be described as the convolution between the classical histogram and the fuzzy membership function[44].

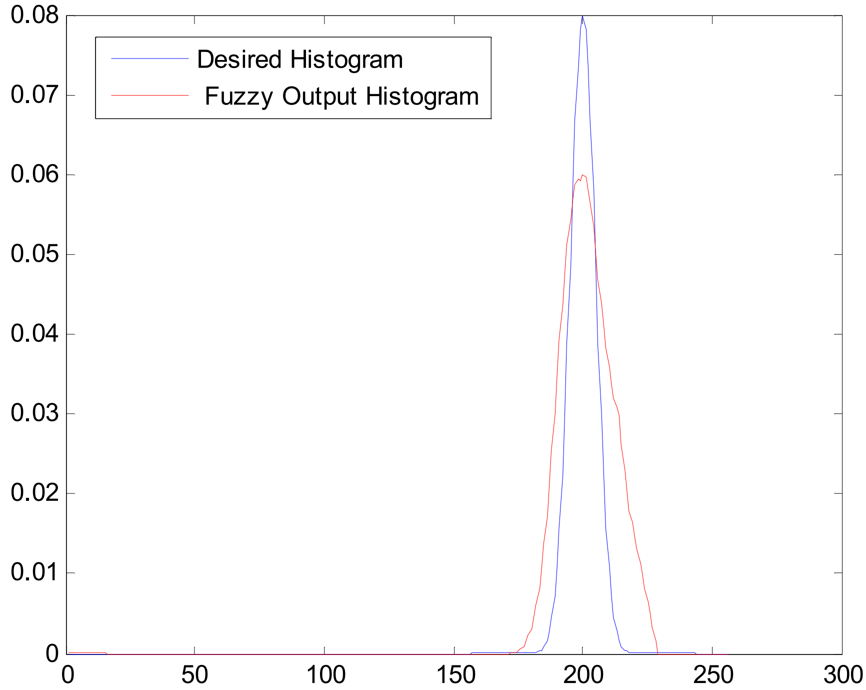
In Section 3.1.3, it is explained that the desired histogram and the output of the histogram specification procedure is not matched exactly. If the fuzzy histogram is used in the output of the specification procedure, the output becomes more close to desired histogram.

In Figure 3.6, the histogram specification procedure with fuzzy histogram is shown.



(a) Input Histogram

Figure 3.6 : The histogram specification procedure with fuzzy histogram



(b) The output of histogram specification procedure

Figure 3.6 : Cont'd

3.1.6 Curvature Scale Space

To apply ring-partitioned method to triangle signs, the circumscribed circle of the triangle signs must be determined. To determine the circumscribed circle, the corner points of the triangle must be known.

In this thesis, the Curvature Scale Space with Adaptive Threshold and Dynamic Region of Support technique is used.

Curvature can be defined as [45]

$$\kappa(\mu,\sigma) = \frac{\dot{X}(\mu,\sigma)\ddot{Y}(\mu,\sigma) - \ddot{X}(\mu,\sigma)\dot{Y}(\mu,\sigma)}{(X(\mu,\sigma)^2 - Y(\mu,\sigma)^2)^{1.5}} \tag{3.16}$$

where $\dot{X}(\mu,\sigma) = x(\mu) * \dot{g}(\mu,\sigma)$, $\ddot{X}(\mu,\sigma) = x(\mu) * \ddot{g}(\mu,\sigma)$, $\dot{Y}(\mu,\sigma) = x(\mu) * \dot{g}(\mu,\sigma)$, $\ddot{Y}(\mu,\sigma) = y(\mu) * \ddot{g}(\mu,\sigma)$ and $*$ is the convolution operator. $g(\mu,\sigma)$ denotes a Gaussian function with deviation σ and $\dot{g}(\mu,\sigma)$ and $\ddot{g}(\mu,\sigma)$ are the first and second derivatives of$g(\mu,\sigma)$.

The original CSS algorithm to detect corners of an image uses the following steps [46]:

1) Canny Edge Detector [47] is applied to the gray level image and a binary edge-map is obtained.
2) The edge contours are extracted from the edge-map, the gaps between these contours are filled. The T-junctions in these corners are determined.
3) For each edge contour, curvature computed at a high scale.
4) Local maxima as initial corners which absolute curvature are above certain threshold are considered as corner candidates .
5) These corners are tracked from the highest scale to the lowest scale to improve localization.
6) To remove the T-junction, the other corners are compared with these junctions and remove one of the two corners, which are very close.

The original CSS algorithm is a single scale. Low scale is used for detection procedure and localization is improved by using multiscale. If σ chosen is large, false corners can be detected and If σ is chosen small, true corners may not be detected [45]

The CSS algorithm in [48] differs from the original CSS in Steps 3&4

3) Compute curvature at a fixed low scale for each contour to retain all true corners.
4) All of the curvature local maxima are considered as corner candidates, including the false corners. By classifying the false corners into rounded and due to boundary noise, two criteria are used to remove them.

Two criteria used in Step 4 are Adaptive local threshold and Angle of corner

Among the corner candidates, rounded corners cause the measurable differences in curvature between this maximum and its neighbors in the region of support. We can eliminate rounded corners by using an adaptive local curvature threshold. In this criterion, the threshold for a candidate is adjusted with respect to its curvature of neighborhood region. The local maxima are under its local threshold are eliminated. This criterion is given by:

$$T(u) = C \times \bar{\kappa} = 1.5 \times \frac{1}{L1+L2+1} \sum_{i=u-L2}^{u+L1} \kappa(i) \quad (3.17)$$

Where $\bar{\kappa}$ is the curvature of a neighborhood, region u is the position of corner candidate in the curve, The points between L1 and L2 are the region of support, and C is a coefficient.

In general, a corner should have a sharp angle. By using the angle of each point on a curve, true corners can be distinguished from false corners.

Consider the case as shown in Figure 3.7.After the local thresholding, corner candidate 2 and 4 are eliminated because of rounded corners. Candidate 3 is a false corner due to boundary noise. The Region of interest for point 3 should be between from corner candidate 1 to 5.

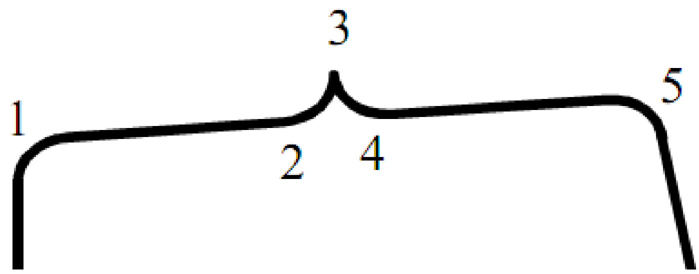


Figure 3.7 : An example case

The Corner checking criteria is given by

$$If\ 160° \leq \ \angle C_i \ \leq \ 200°, then\ C_i\ is\ a\ false\ corner$$
$$Else\ C_i\ is\ a\ true\ corner$$

$\angle C_i$ is given by

$$\angle C_i = \left|\tanh^{-1}\frac{\Delta Y1}{\Delta Y1} - \tanh^{-1}\frac{\Delta Y2}{\Delta Y2}\right|$$

Where

$$\Delta X1 = \frac{1}{L1}\sum_{i=u+1}^{U+l1} X(i) - X(u)$$
$$\Delta X2 = \frac{1}{L2}\sum_{i=u-l2}^{u-1} X(i) - X(u)$$
$$\Delta Y1 = \frac{1}{L1}\sum_{i=u+1}^{U+l1} Y(i) - Y(u)$$
$$\Delta Y2 = \frac{1}{L2}\sum_{i=u-l2}^{u-1} Y(i) - Y(u)$$

3.1.7 Circular Hough Transform

To detect circular traffic signs, circular Hough transform (CHT) is used.

In the classical Hough transform the identification of lines in the image is considered, but later the Hough transform is modified to detect arbitrary shapes like circles or ellipses.

The equation of a circle is defined as

$$r^2 = (x - a)^2 + (y - b)^2 \tag{3.18}$$

A circle can be represented with three parameters, r, a and b. Where a and b are the center points of the and r is the radius.

CHT procedure can be explained as:

- Edges of the image is obtained by using Canny Edge Detector.

- Draw a circle on the accumulator matrix, for each edge point. The accumulator matrix is increased by one for each point of the circle.
- The local maximum of accumulator matrix is chosen as the center of the circle.

CHT procedure is shown in Figure 3.8 [49]

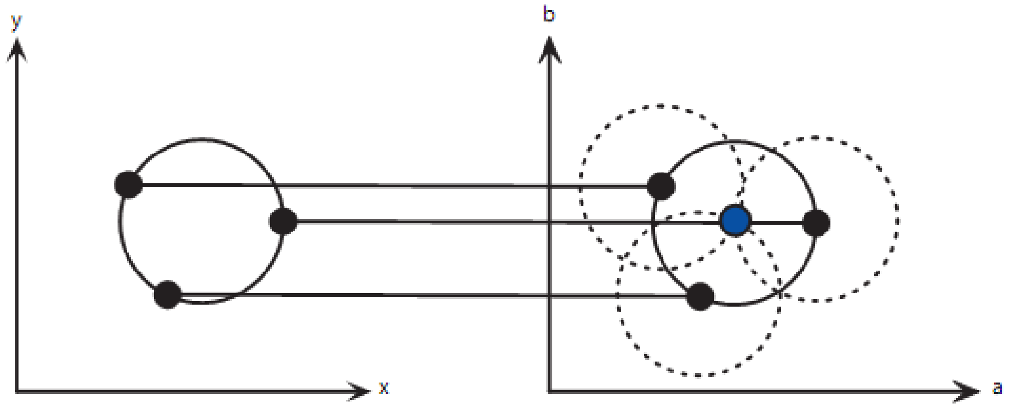


Figure 3.8 : Mapping in CHT

In Figure 3.8, at each edge point a circle is drawn with center in the point with the desired radius. The size of accumulator space is the same with the parameter space. The maxima in the accumulator space is the center point of a circle.

3.2 Ring-Partitioned Method

3.2.1 Specified Gray Scale Image

The traffic signs are outdoor objects so they can exposure different illumination, and lightning conditions. The Ring-Partitioned method is a histogram-based method. Using the histograms of traffic signs without any change is not a feasible solution since due to different illumination conditions; even the same type of traffic signs can seem different. To overcome this problem, the specified gray scale image is used in ring-partitioned method.

In this thesis, the signs that contain red, blue, black and white color are considered. For each color, the color segmentation is applied. The color segmentation methods are explained in 3.1.2.

After the color segmentation, a gray scale image for each color can be obtained. There are four different histograms for each gray scale image. By using, the histogram specification technique explained in 3.1.3, each gray scale histogram is transformed to a pre-determined histogram. If the different gray scale range is determined in pre-determined histograms, the four gray scale images can be combined into an image where grayscale range for red, blue, white and black colors are definitely separated. The same pre-determined histograms are used for black and blue colors because only square signs contain both these color. In square signs, pre-determined histograms for black and blue color do not affect the performance of the algorithm.

This image is called as “Specified gray scale image” and is robust to illumination changes.

The specified gray scale stage of the ring-partitioned method can be summarized as:

1. The input image is an RGB image and at the beginning, this input image is resized to 80x80 pixels image. The input image is shown in Figure 3.9.

Figure 3.9 : Input Image

2. The color segmentation is applied for blue, red, white and black colors. Color segmentation is shown in Figure 3.10.

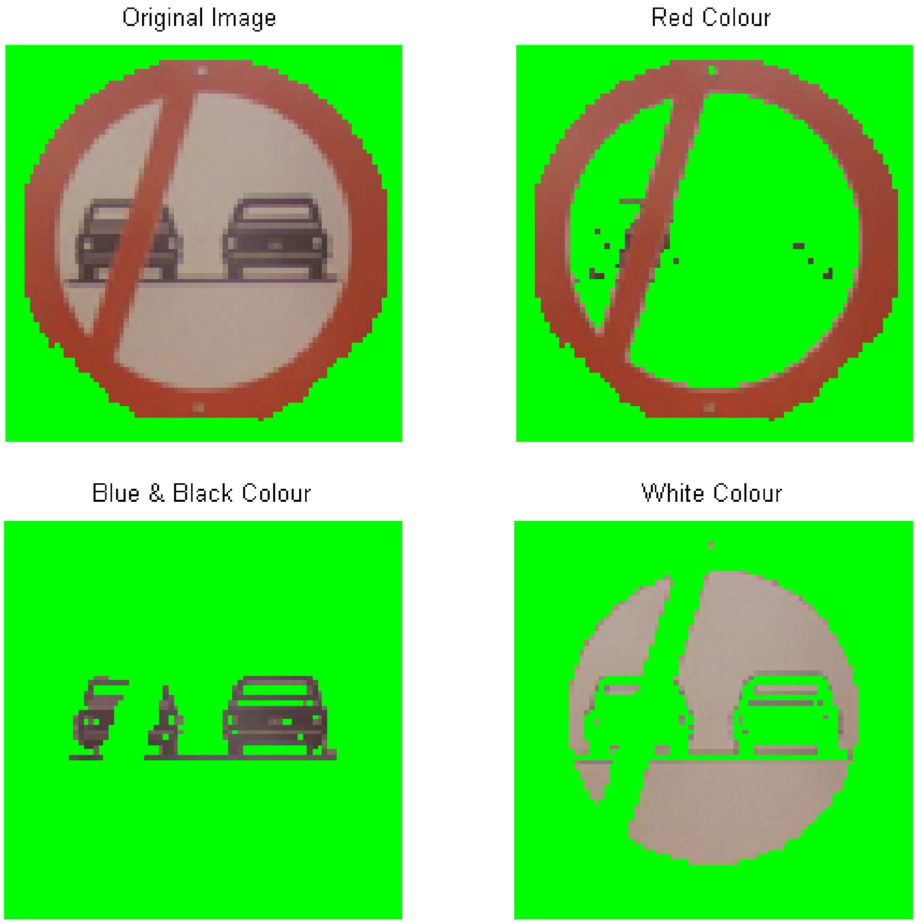
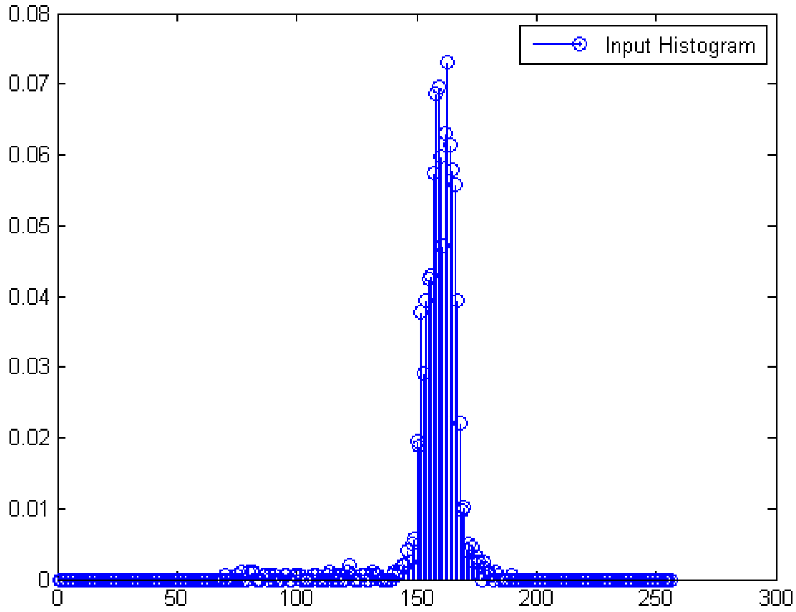
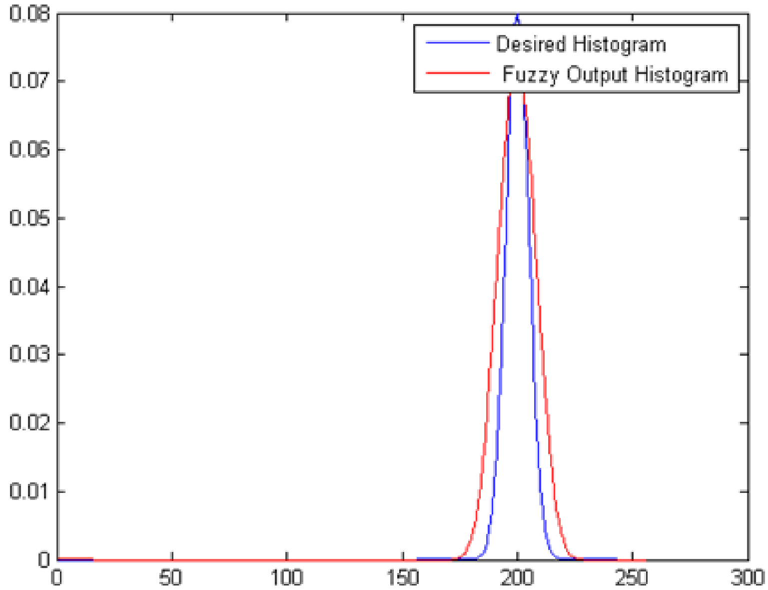


Figure 3.10 : Color Segmentation

3. Histogram specification is applied to each color-segmented image. In each histogram specification, different pre-determined histograms are used. In Figure 3.11-3.13, the histogram specification results are shown. There is no histogram specification result for blue color because there is no blue color in the input image.

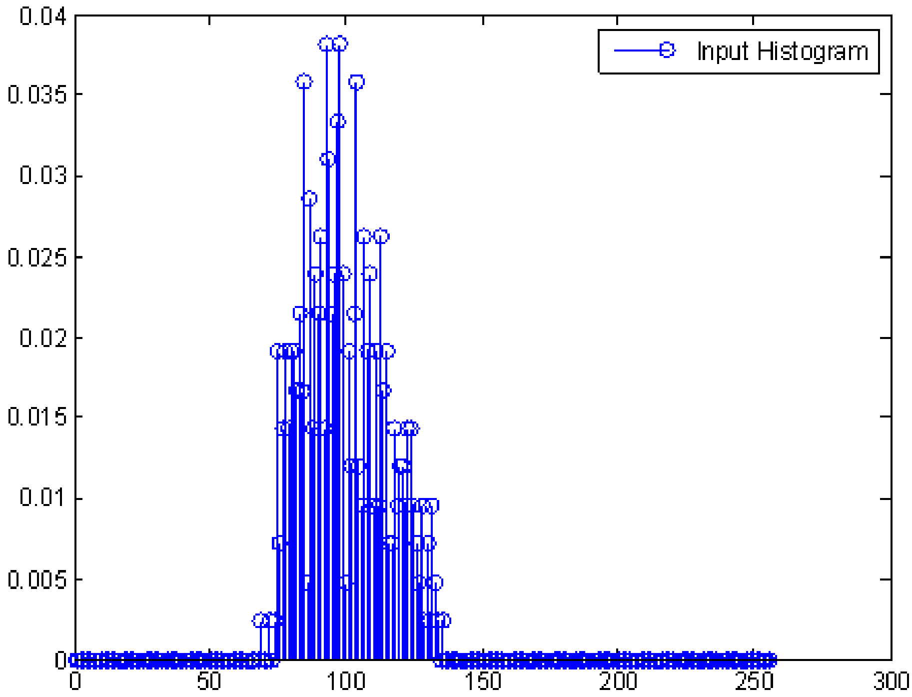


(a) Input Histogram

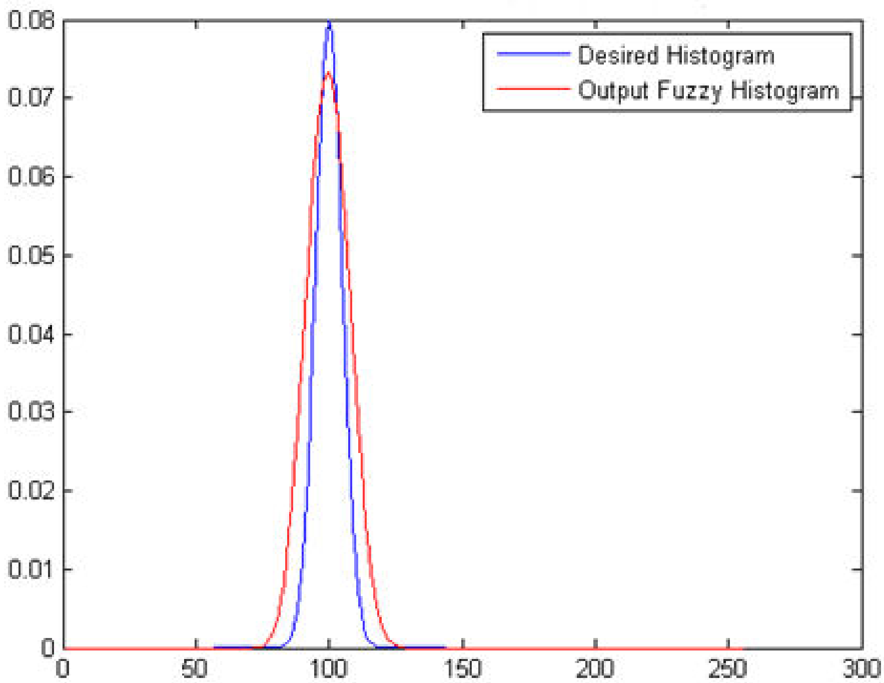


(b) Histogram Specification

Figure 3.11 : Red Color Segmentation

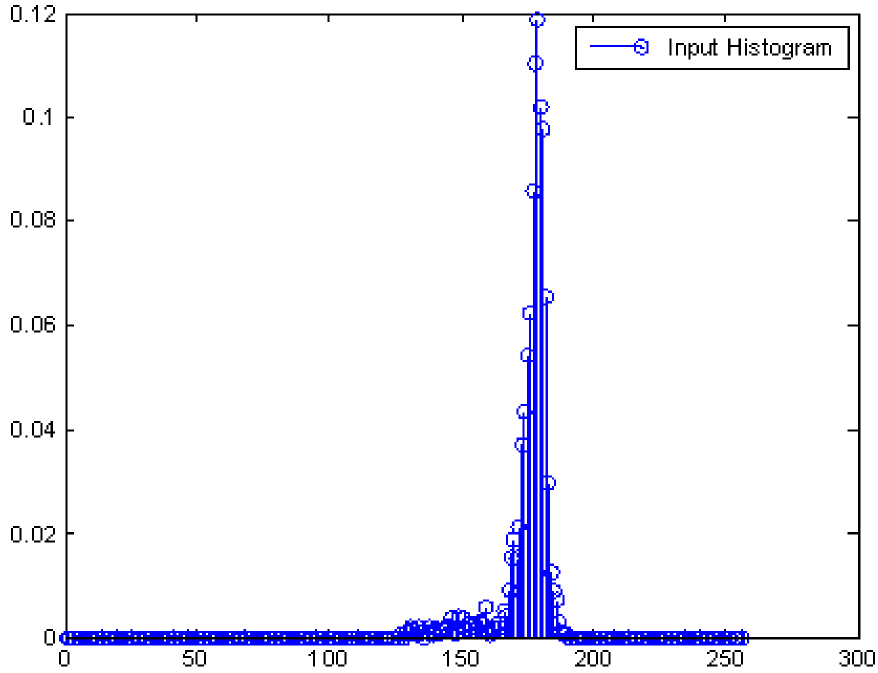


(a) Input Histogram

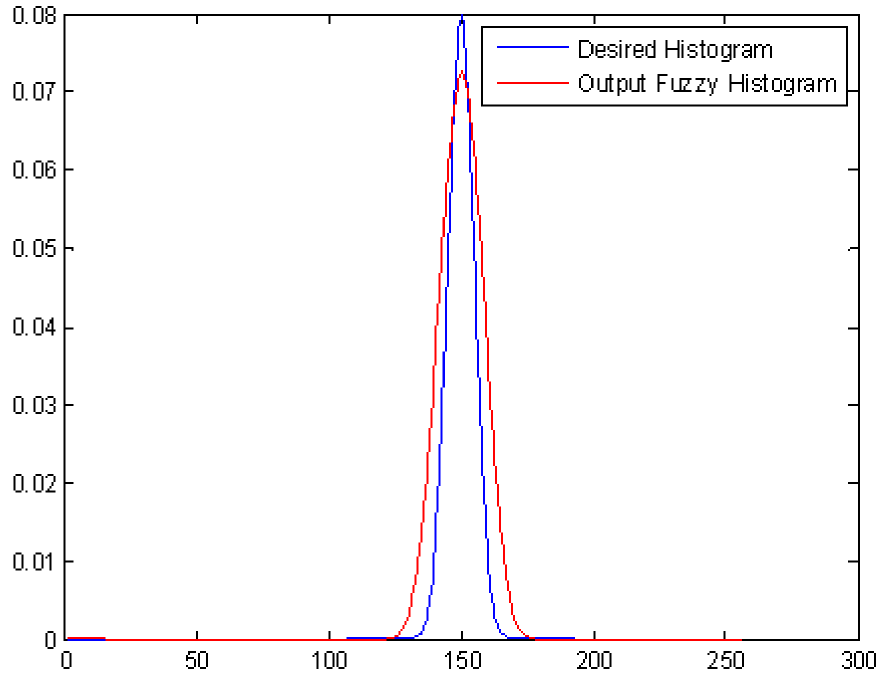


(b) Histogram Specification

Figure 3.12 : Black and Blue Color Segmentation



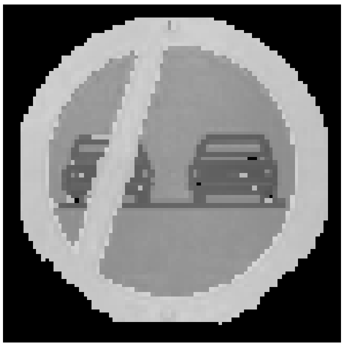
(a) Input Histogram



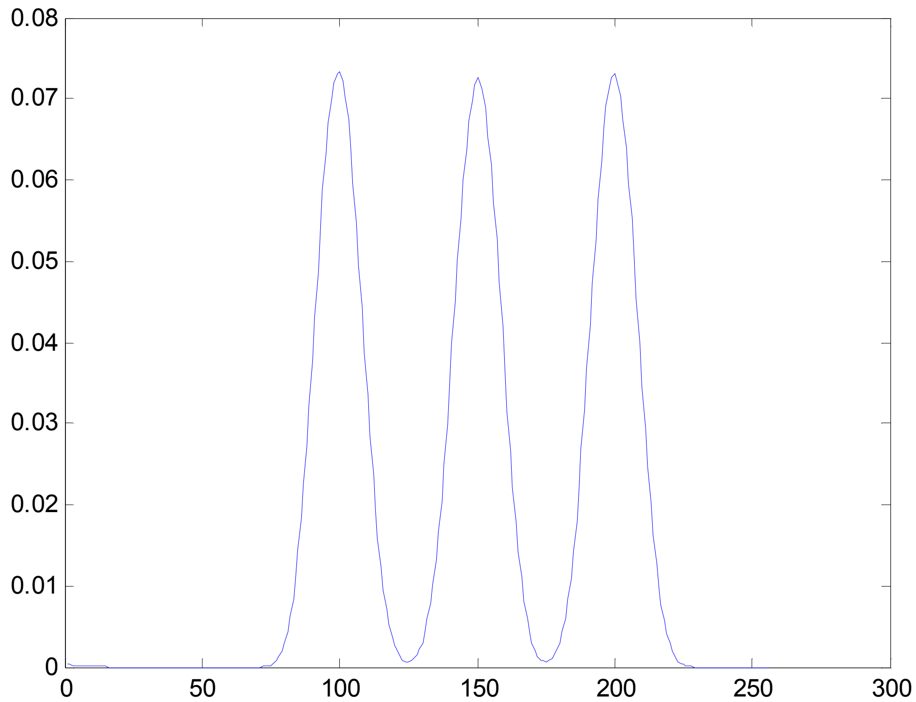
(b) Histogram Specification

Figure 3.13 : White Color Segmentation

4. The output histograms of the histogram specified is combined and the specified gray scale image is obtained. In Figure 3.14, the specified gray scale image and corresponding histogram is shown.



(a) The specified gray scale image



(b) The histogram

Figure 3.14 : The specified gray scale image and corresponding histogram

3.2.2 Partitioning Stage

The histogram of an image does not carry spatial information. Different images can have the same histograms so comparing histograms directly does not make sense. In Ring Partitioned method, the histogram is divided into partitions and the histogram of these partitions is used for comparison. In Ring Partitioned method, these partitions are ring shaped. In Figure 3.15, the rings are shown.

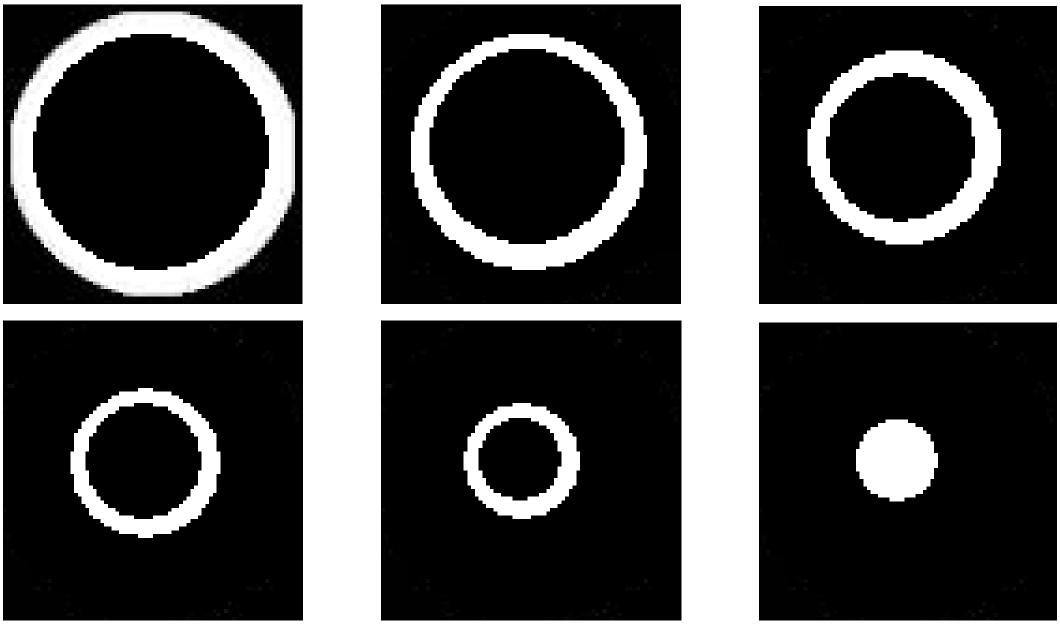


Figure 3.15 : Ring Partitions

Another advantage of ring partitions is to provide robustness for classification of rotated circle traffic signs. Determining rotation in circular traffic signs is not a trivial task. Circle has no corner so in detection stage there is no chance to determine whether it is rotated or not. For square and triangle signs, by using the corner point information, in the detection stage the rotation rate can be determined. In classification stage, the rotation problem in circle signs must be considered. In ring-partitioned method, if the sign is rotated, the histogram of the ring partitions will be same with the unrotated sign. Therefore, there is no difference between rotated and unrotated sign in ring-partitioned methods.

3.2.3 Matching Stage

The partitioned histograms for each reference signs are stored in a database. The partitioned histograms of an input sign is compared with each reference sign in the database. The aim of matching stage is to find the reference image, which has the lowest distance to the input image.

The Euclidean distance is used to calculate the distance between target and reference image. The distance between target and reference image is calculated as:

$$d^{TR} = \sqrt{(TH_1 - RH_1)^2 + \cdots + (TH_k - RH_k)^2} \quad (3.19)$$

Where $\mathrm{TH_i}$ is the histogram result of input image of ring i and $\mathrm{RH_i}$ is the the histogram result of reference image of ring i.

The reference image with the lowest distance is selected as the type of input image.

3.3 Detection of Circular Signs

In section 3.2, we assume that the input image is a traffic sign that is extracted from a traffic scene image. For the real traffic sign recognition system, the input image is obtained from detection stage. The scope of this thesis is just the classification stage of a TSR system. However, to evaluate the performance of the classification stage, the detection algorithms are implemented. The whole traffic scene image is not used as an input of detection stage. The background of the whole traffic scene image is reduced so this makes the detection easier.

To detect circular traffic signs, Circular Hough transform is used. The Circular Hough Transform is explained in section 3.1.7 .In Figure 3.16, Detection steps of circular signs are shown.

(a) Traffic Scene Image

(b) The Result of CHT

Figure 3.16 : Detection of Circular Signs

(c) The output of CHT

Figure 3.16 : Cont'd

3.4 Detection of Triangle Signs

To detect triangle signs, both color-based and shape-based methods are used. Firstly, Curvature Scale Space method is applied to reduced traffic scene image so the corner points can be found. However, we are interested in corner points of the triangle signs. To separate corner points of the triangle signs from irrelevant corner points, we have used color-based approach. We look red pixels at the neighborhood of each corner points. If the number of red pixel points is between the pre-determined thresholds, we can classify this corner point as a corner of triangle.

After the corner points are found, the circumscribed circle of this triangle can be found. Circumscribed circle is explained in section 3.1.4.

In Figure 3.17, Detection steps of triangle signs are shown.

(a) All corners of Traffic Scene Image

(b) The corners of Traffic Sign

Figure 3.17 : Detection of Triangular Signs

(c) The output of Detection

Figure 3.17 : Cont'd

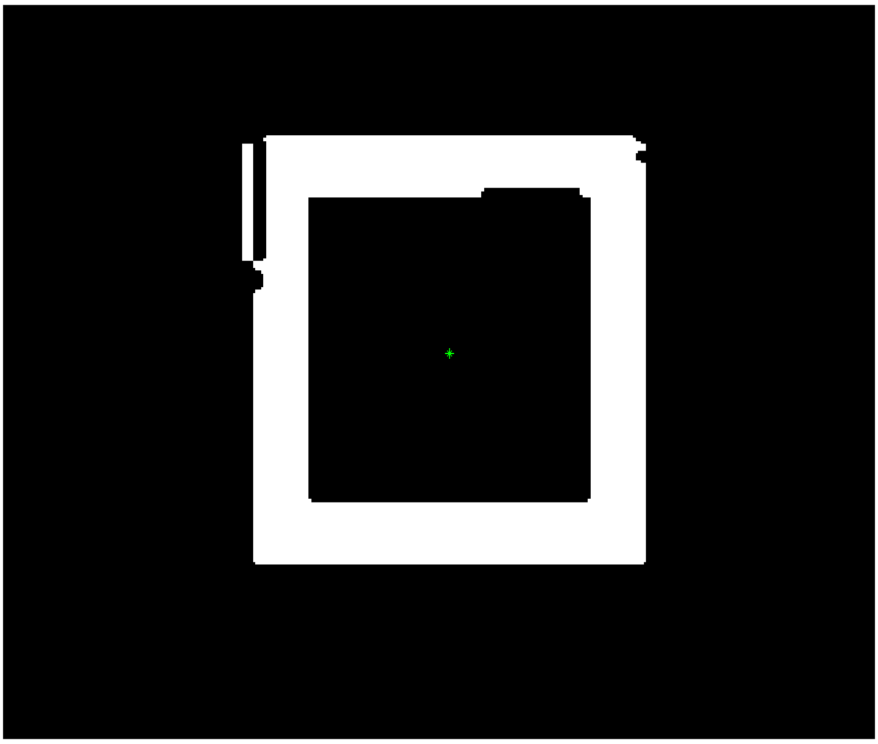
3.5 Detection of Informational Square Signs

To detect informational square signs, color-based method is used. The Turkish informational square traffic signs contain blue and white color. The backgrounds of this type of square signs are blue and pictograms of the square signs are white. By using the blue background color, the square signs can be detected. The blue color segmentation method explained in section 3.1.2 is used to detect blue color detection. After the blue color is segmented, the largest blue colour region is selected as the square traffic sign. After the traffic sign region is found, the centroid of the sign and corresponding circumscribed circle can be determined.

After the circumscribed circle is determined, the ring partitioned method is applied.

In Figure 3.18, detection steps of square signs are shown

(a) The Traffic Scene Image



(b) The Blue color segmentation

Figure 3.18 : The detection of Square Signs

(c) The output of Detection

Figure 3.18 : Cont'd

CHAPTER 4

EXPERIMENTAL RESULTS

In this chapter, we present some experimental results obtained from the implementation of Ring Partitioned Method. The method is tested with circle, triangle and square Turkish Traffic Signs. In this chapter, 5 different data sets are used and 8 different experiments are implemented by using these data sets.

4.1 Data Sets

Five different data sets are used. These data sets contain circle, triangle and square Turkish signs.

4.1.1 Data Set 1

This data set contains real and synthetic circular traffic sign images. Real traffic scene images are taken in Ankara by using 1.3 MP cell phone camera. Traffic sign images are extracted from traffic scene image by using Photoshop. In Figure 4.1, the traffic scene image and corresponding extracted traffic sign image is shown.

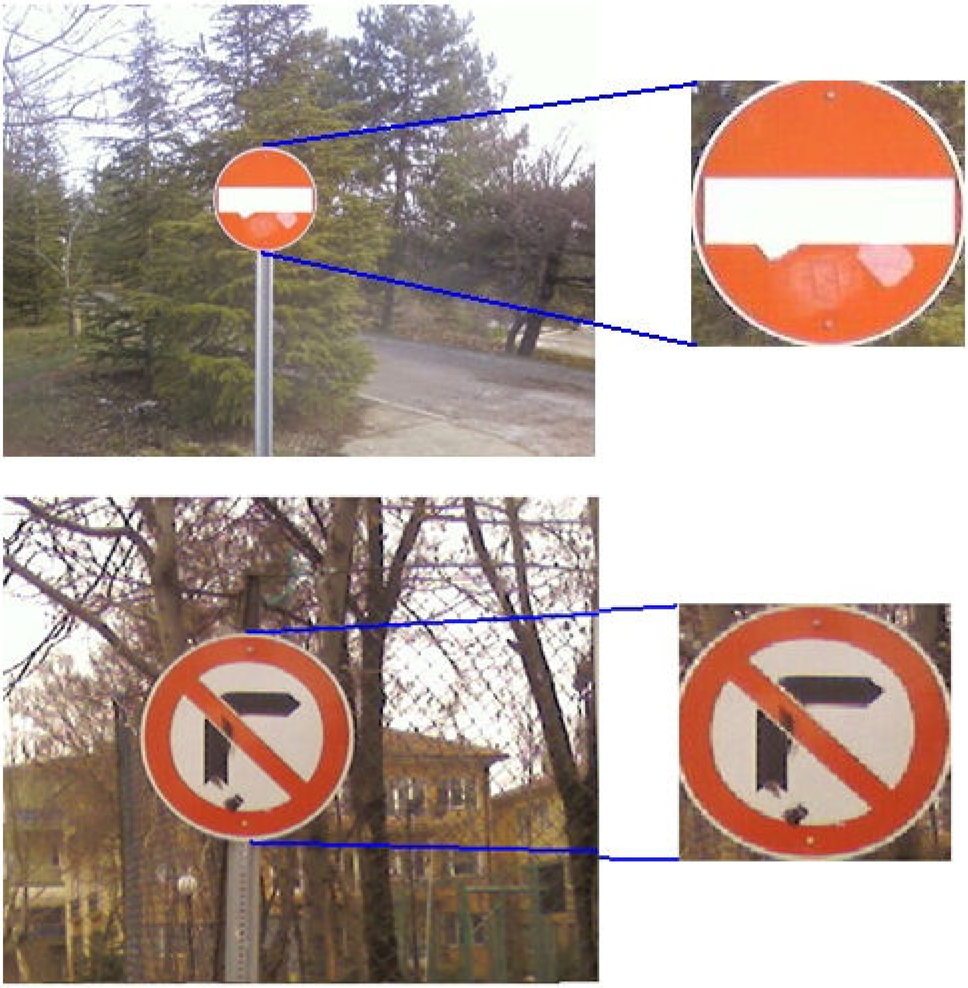


Figure 4.1 : Traffic Scene Image and Corresponding Extracted Traffic Sign

Data Set 1 also contains synthetic circular traffic signs. These images are taken from the internet. Some traffic signs are very rare and hard to find so instead of using real signs, synthetic signs are used. The examples of synthetic signs are shown in Figure 4.2.

Figure 4.2 : Synthetic Traffic Signs

Data Set 1 contains 186 circular traffic sign images. There are 45 synthetic and 141 real images in the Data Set. There are 33 different types of circular traffic sign images in Data Set 1. Some examples of Data Set 1 images are shown in Figure 4.3.

Figure 4.3 : Data Set 1

4.1.2 Data Set 2

This data set contains real traffic scene images for circular signs. Traffic scene images consist of traffic sign and background of the traffic sign. But in this data set, entire traffic scene images are not used. The background of the traffic scene image is reduced because the extraction of traffic sign from entire traffic scene image is the subject of detection stage of the traffic sign recognition system. The detection stage is out of the scope of this thesis. In Figure 4.4, the traffic scene image and corresponding reduced traffic scene is shown.

(a) Traffic scene image

(b) Reduced Traffic scene image

Figure 4.4 : The traffic scene image and corresponding reduced traffic scene

Data Set 2 contains 110 circular traffic sign images. There are 12 different types of circular traffic sign images in Data Set 2. Some examples of Data Set 2 images are shown in Figure 4.5.

Figure 4.5 : Data Set 2

4.1.3 Data Set 3

This data set contains real traffic scene images for triangular signs. In this data set, the background of the traffic scene image is reduced like data set 2.

Data Set 3 contains 70 triangular traffic sign images. There are 10 different types of triangular traffic sign images in Data Set 3. The examples of Data Set 3 images are shown in Figure 4.6.

Figure 4.6 : Data Set 3

4.1.4 Data Set 4

This data set contains real and synthetic traffic scene images for square signs. In this data set, the background of the traffic scene image is reduced like data set 2 and data set 3.

Data Set 4 contains 20 square traffic sign images. There are 5 different types of square traffic sign images in Data Set 4. The examples of Data Set 4 images are shown in Figure 4.7.

Figure 4.7 : Data Set 4

4.1.5 Data Set 5

This data set contains real traffic scene images captured from a video sequence. These images contain circle, triangle and square signs. In this data set, the background of the traffic scene image is reduced like data set 2 and data set 3.

Data Set 5 contains 73 circle, 29 triangle and 21 square traffic sign images. The examples of Data Set 5 images are shown in Figure 4.8

Figure 4.8 : Data Set 5

4.2 Experiments

4.2.1 Experiment 1

In this experiment, the ring partitioned method is applied to Data Set 1. The aim of this experiment is to analyze the performance of the method for perfectly extracted circular traffic signs. As mentioned in Data Set 1, the border of the traffic signs are extracted by using Photoshop so the traffic signs in Data Set 1 can be considered as perfectly extracted traffic signs. By using perfectly extracted signs, the performance of classification method can be evaluated without considering detection errors.

The results of the experiment is given in Table 4.1

Table 4.1 : The result of Experiment 1

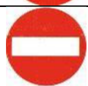
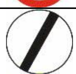
	Sign	# of Signs	# of Correct Recognition	Incorrect Matching
1		4	4	
2		1	1	
3		1	1	
4		4	3	
5		1	1	
6		20	20	
7		13	12	
8		12	10	 
9		14	13	
10		2	2	

Table 4.1 : Cont'd

	Sign	# of Signs	# of Correct Recognition	Incorrect Matching
11		2	2	
12		4	3	
13		1	1	
14		3	2	
15		1	1	
16		1	1	
17		7	7	
18		13	11	 
19		7	7	
20		12	12	
21		15	14	
22		2	2	
23		15	13	 
24		5	5	
25		3	3	
26		3	2	
27		2	2	
28		10	9	
29		3	3	
30		1	1	
31		1	1	
32		1	1	
33		2	2	
	Total	186	172	
Recognition Percentage = 92%				

The success rate of the method is 92%. Most of the errors are in the real images part of the data set because real traffic images are affected by varying illumination, noise or other factors like deformation.

4.2.2 Experiment 2

In this experiment, the ring partitioned method is applied to Data Set 2.The aim of this experiment is to analyze the performance of the method with a detection algorithm. In Experiment 1, the perfectly extracted signs are used. But in real applications, the input of the classification stage is not perfectly extracted.

For this reason, Circular Hough Transform is applied to the traffic scene image before the ring partitioned method. In this experiment, Hough transform can be considered as detection stage of traffic sign recognition system. For real applications, Circular Hough transform is not sufficient to detect signs from a traffic scene image. But for our experiment Circular Hough transform is sufficient, because as mentioned in Data set 2, the background of the traffic scene image is reduced so this makes the detection easier. In Figure 4.9, the traffic scene image and the detected traffic sign by using Hough transform is shown.

Figure 4.9 : Traffic Scene Image and Detected Traffic Sign

The reference images must be standard traffic signs without any distortion. For this reason, in experiment 2, traffic sign images in data set 1 are used as reference images for ring partitioned method.

The results of the experiment is given in Table 4.2

Table 4.2: The result of Experiment 2

	Sign	# of Signs	# of Correct Recognition	Incorrect Matching
1		20	20	
2		8	8	
3		12	9	  
4		8	8	
5		7	7	
6		7	6	
7		6	5	
8		10	7	  
9		11	10	
10		8	7	
11		7	7	
12		3	3	
	Total	107	97	
Recognition Percentage = 91%				

4.2.3 Experiment 3

In this experiment, the ring partitioned method is applied to Data Set 3. To apply ring partitioned method to triangular signs, the corner points of the triangular signs must be known. If corner points of the triangle are known, the circumscribed circle of the triangle can be found. After finding the circumscribed circle of the triangle, the ring filters can be applied to sign like circle signs. Circumscribed circle of triangle is shown in Figure 4.10.

The aim of this experiment is to evaluate the performance of the ring-partitioned method when corner points of the triangle traffic sign are known exactly. The coordinates of the corner point for each sign is determined before the method is applied and they are stored in a database. When the method is running, corner points in the database are used.

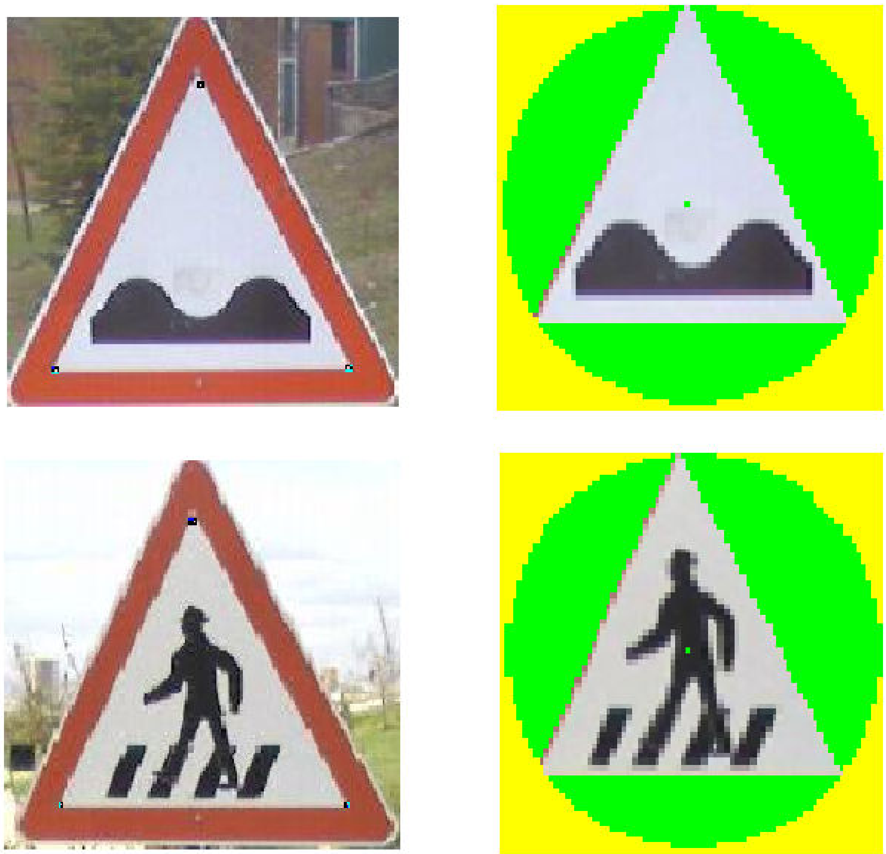


Figure 4.10 : Triangle Traffic sign and Circumscribed circle

The results of the experiment are given in Table 4.3

Table 4.3: The result of Experiment 3

	Sign	# of Signs	# of Correct Recognition	Incorrect Matching
1		11	10	
2		3	2	
3		6	6	
4		3	3	
5		3	2	
6		14	13	
7		13	12	
8		3	3	
9		11	10	
10		3	2	
	Total	70	62	
	Recognition Percentage = 88%			

4.2.4 Experiment 4

In this experiment, the ring partitioned method is applied to Data Set 3. As mentioned before the corner points of the triangular signs must be known to apply ring partitioned method to triangular signs.

In this experiment "Curvature Scale Space with Adaptive Threshold and Dynamic Region of Support Method" is used to find corners in the traffic scene image. The output of this method contains all corner points in the traffic scene image but we are interested in corner points of the triangle traffic signs

In Figure 4.11, all corners in traffic scene image and corners of the triangle sign image are shown:

(a) All corners in traffic scene image

(b) Corners of the triangle sign

Figure 4.11 : Corners of the triangle sign

The results of the experiment is given in Table 4.4

Table 4.4: The result of Experiment 4

	Sign	# of Signs	# of Correct Recognition	# of Unlabeled Signs	Incorrect Matching
1		11	9		
2		3	2		
3		6	5	1	
4		3	2	1	
5		3	2		
6		14	13		
7		13	6	1	
8		3	1	2	
9		11	9		
10		3	2		
	Total	70	51		
	Recognition Percentage = 72%				

4.2.5 Experiment 5

In this experiment, the ring partitioned method is applied to Data Set 4. To apply ring partitioned method to square signs, the corner points of the square signs must be known. If corner points of the square are known, the circumscribed circle of the square can be found. After finding the circumscribed circle of the square, the ring filters can be applied to sign like circle signs.

The aim of this experiment is to evaluate the performance of the ring-partitioned method when corner points of the square traffic sign are known exactly. The coordinates of the corner point for each sign is determined before the method is applied and they are stored in a database. When the method is running, corner points in the database are used.

The results of the experiment is given in Table 4.5

Table 4.5: The result of Experiment 5

	Sign	# of Signs	# of Correct Recognition	Incorrect Matching
1		3	3	
2		2	2	
3		11	10	
4		2	2	
5		2	2	
	Total	20	19	
Recognition Percentage = 95%				

4.2.6 Experiment 6

In this experiment, the ring partitioned method is applied to Data Set 4. To apply the ring partitioned method to square traffic sign, the circumscribed circle of the sign must be known.

To find the borders of the square traffic sign, the colour based detection method is used. The square traffic signs are not perfect squares because their corners are round. Square with round corners make the corner detection algorithm inefficient. In Figure 4.12, the output of the corner detection algorithm for square traffic sign is shown. In Experiment 6, the colour based detection method is used instead of corner detection method.

Figure 4.12 : The output of the corner detection algorithm

In the colour based detection method, the colour segmentation for blue colour is applied to traffic scene image. It is assumed that the largest blue colour region is the square traffic sign. After the traffic sign region is found, the centroid of the sign and corresponding circumscribed circle can be determined. It must be mentioned that such a detection algorithm is not sufficient for a real traffic sign recognition system. In Figure 4.13, the detection process for square traffic sign is shown.

Figure 4.13 : Detection Process for Square Traffic Square Signs

The results of the experiment are given in Table 4.6

Table 4.6: The result of Experiment 6

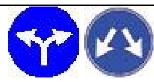
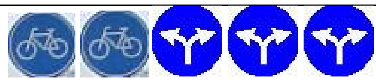
	Sign	# of Signs	# of Correct Recognition	Incorrect Matching
1		3	3	
2		2	2	
3		11	9	 
4		2	2	
5		2	2	
	Total	20	18	
Recognition Percentage = 90%				

4.2.7 Experiment 7

In this experiment, the ring partitioned method is applied to Data Set 5. Data Set 5 contains circular, triangular and square traffic scene images. For circular signs, CHT is applied to the traffic scene image before the ring partitioned method like in Experiment 2. For triangular signs, corner point of the traffic sign is found before the ring partitioned method like in Experiment 4. For square signs colour based detection algorithm is applied to the traffic scene image before the ring partitioned method like in Experiment 6.

The result of the experiment for circle signs is given in Table 4.7.

Table 4.7 : The result of Experiment 7 for Circular Signs

	Sign	# of Signs	# of Correct Recognition	Incorrect Matching
1		9	9	
2		4	4	
3		9	7	
4		10	9	
5		5	5	
6		10	8	
7		13	8	
8		5	4	
9		8	8	
	Total	73	62	
Recognition Percentage = 85%				

The result of the experiment for triangular signs is given in Table 4.8

Table 4.8 : The result of Experiment 7 for Triangular Signs

	Sign	# of Signs	# of Correct Recognition	# of unlabeled	Incorrect Matchings
1		6	4		 
2		10	5	2	  
3		8	6	2	
4		1	1		
5		4	3	1	
	Total	29	19		
Recognition Percentage = 65%					

The result of the experiment for square signs is given in Table 4.8

Table 4.9 : The result of Experiment 7 for Square Signs

	Sign	# of Signs	# of Correct Recognition	Incorrect Matching
1		4	3	
2		11	9	 
3		6	5	
	Total	21	17	
Recognition Percentage = 80%				

4.2.8 Experiment 8

As explained in chapter 3, the ring partitioned method contains three stages:

- Specified Gray Scale Image
- Partitioning Stage
- Matching Stage

In this experiment, the contribution of these stages is analyzed. To analyze this stage, one of the stages is changed partially or totally while other stages remain unchanged so the contribution of each stage can be analyzed separately.

In this experiment, Data Set 1 which contains the perfectly extracted circular traffic signs is chosen because using the detection process might affect the performance of the experiment.

In experiment 8, three different variations are used. In the first variation, the method is applied to data set without ring partitioned method. In other words, the histogram of the specified gray scale and the histogram of the reference image are compared. In the second variation; the input image is converted to grey scale instead of specified grey scale. In the third variation, the classical histogram is used instead of fuzzy histogram.

To convert the RGB image to gray scale, Equation (4.1) is used.

$$I = 0.2989 * R + 0.5870 * G + 0.1140 * B \qquad (4.1)$$

In Figure 4.14, the flow chart of the ring partitioned method and the parts of this experiment are shown.

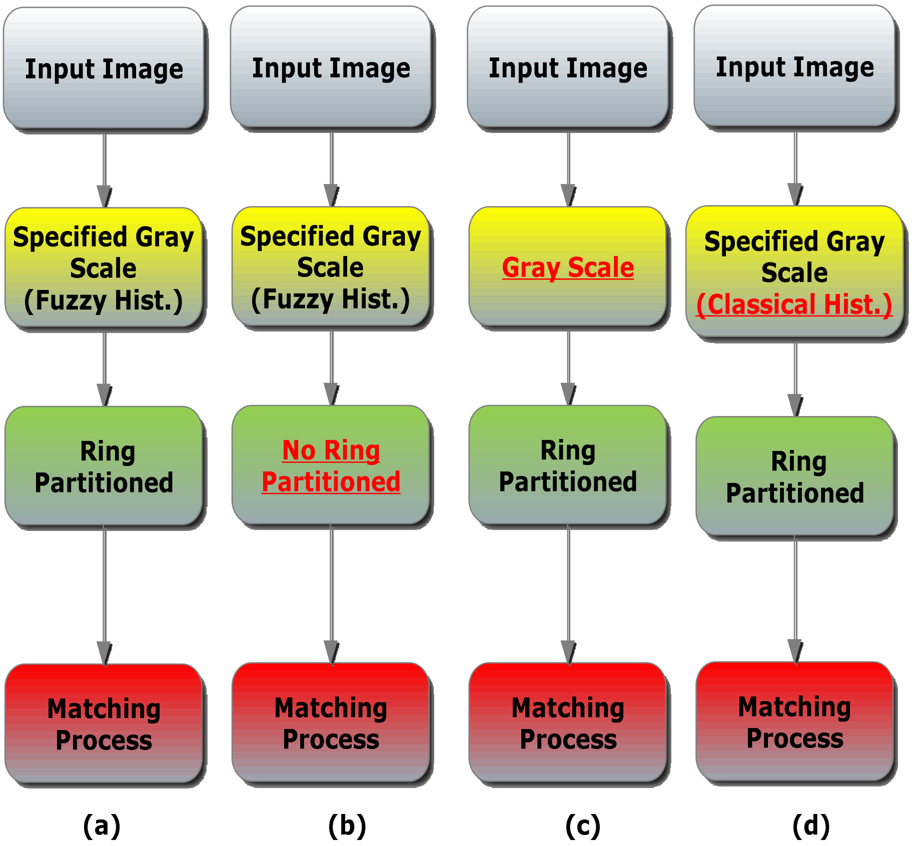


Figure 4.14: The comparison of Ring Partitioned method Stages

The results of the experiment are given in Table 4.10. “Original Method” is the performance of the ring partitioned method without any change. These results are the same with The Experiment 1.

Table 4.10: The result of Experiment 8

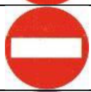
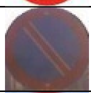
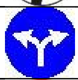
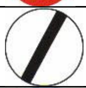
	Sign	# of Signs	Original Method	Without Ring Partitioning	Gray Scale	Classical Hist.
1		4	4	2	1	4
2		1	1	0	1	1
3		1	1	0	0	0
4		4	3	0	1	4
5		1	1	1	1	1
6		20	20	17	3	15
7		13	12	8	2	7
8		12	10	6	2	9
9		14	13	2	3	1
10		2	2	2	0	1
11		2	2	2	1	2
12		4	3	2	0	0
13		1	1	1	0	1
14		3	2	0	2	0
15		1	1	0	0	0
16		1	1	1	0	1
17		7	7	7	1	1
18		13	11	10	0	10
19		7	7	3	2	3

Table 4.10: Cont'd

	Sign	# of Signs	Original Method	No Ring Partitioned	Gray Scale	Classical Hist.
20		12	12	2	4	5
21		15	14	2	0	0
22		2	2	0	0	0
23		15	13	6	2	5
24		5	5	3	0	4
25		3	3	2	2	3
26		3	2	0	0	0
27		2	2	1	0	0
28		10	9	7	2	4
29		3	3	2	3	1
30		1	1	1	0	1
31		1	1	1	1	1
32		1	1	1	0	0
33		2	2	2	1	0
	Total	186	172	94	35	85
	Recognition Percentage		92%	50%	18%	45%

4.3 Analysis of Experimental Results

In this section, the results of the experiments given in section 4.2 will be analyzed

4.3.1 Robustness to Illumination

The traffic signs are outdoor objects so they can be at various illumination conditions. So as mentioned before, the traffic sign recognition system must handle various illumination conditions.

The Ring Partitioned method uses Specified Gray Scale image to overcome illumination problem. The histogram of the same sign can differ at various illumination conditions. In Figure 4.15, the histograms of the same sign at various illumination conditions are given.

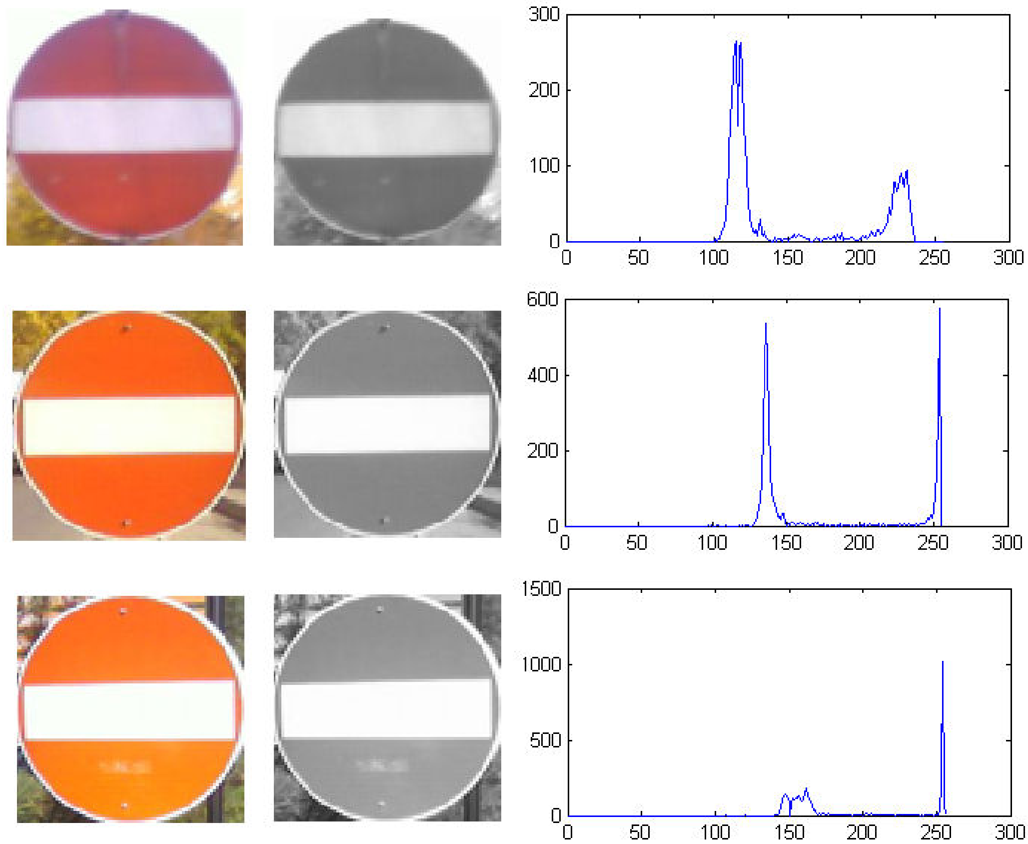


Figure 4.15 : Histograms for Different Illuminated Signs

As seen in Figure 4.15, each of three “STOP” signs is at various illumination conditions and the histogram of their corresponding gray scale image differs. The ring partitioned method uses Specified Gray Scale image instead of gray scale image. Specified Gray Scale comprises a new histogram by using Histogram specification techniques. This new histogram is robust to illumination. In Figure 4.16, the specified gray scale image and corresponding histogram of these images are given.

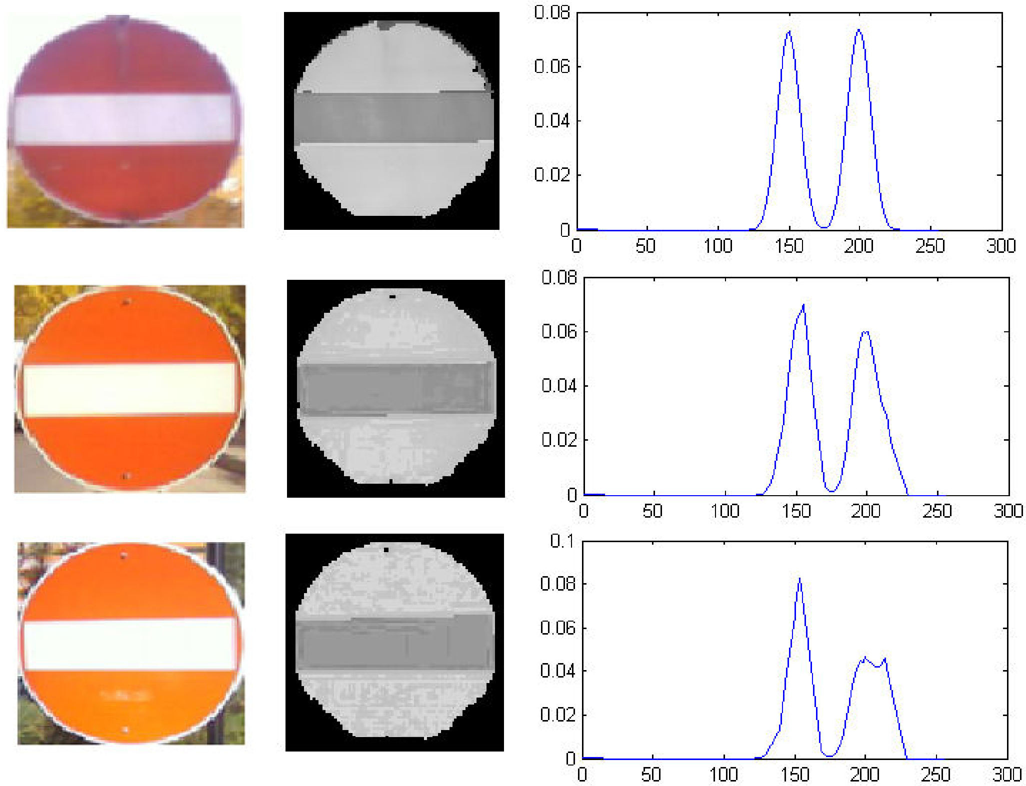


Figure 4.16 : Gray Scale Images for Different Illuminated Signs

As shown in Figure 4.16, the specified gray scale image is nearly the same for the traffic signs at various illumination conditions. While gray scale histograms are different for the traffic signs at various illumination conditions, the histogram of specified gray scale are more close to each other so the histogram of the specified gray scale image is more suitable for comparison of the traffic signs.

4.3.2 Robustness to Rotation

The traffic signs can be at different rotations. So as mentioned before, the traffic sign recognition system must handle traffic signs at different rotations.

The ring partitioned method is a histogram based method. Histogram is a spatial image descriptor so it does not carry any information about rotation. That means the histograms of the same image at different rotations are the same. This property of the histogram makes the ring partitioned method robust to rotations.

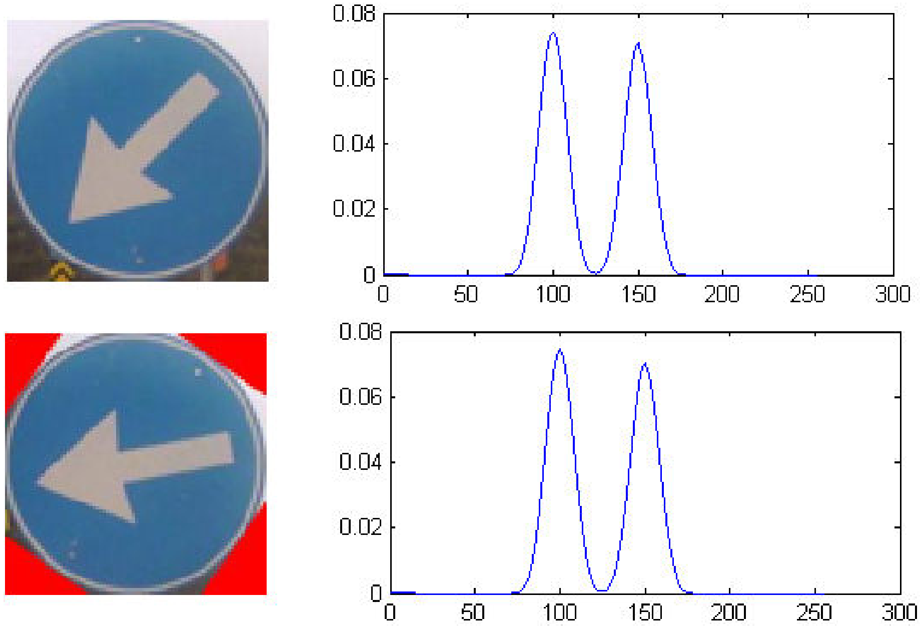


Figure 4.17: Histograms for Rotated Signs

Theoretically, there is no limit for rotation rate. However practical applications limits rotation rate. Some traffic signs have the same histograms (i.e. “Left Turn is not allowed” and “Right Turn is not allowed”). To classify such signals, the distribution of the colors is used. The color distribution of half parts of the traffic signs is compared. If the number of black pixels is greater in left part, the sign can be classified as “Left Turn is not allowed” sign; otherwise, the sign is classified as “Right Turn is not allowed” sign.

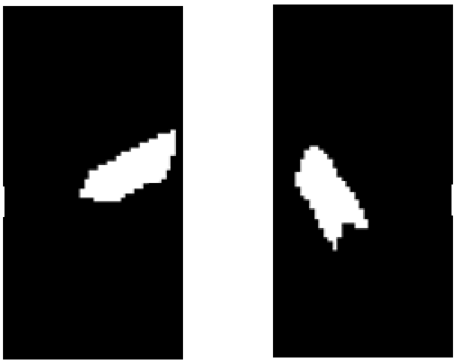
If sign is rotated more than a specified rate, that sign can be misclassified because comparing the half parts of the rotated signs is not suitable for classification. Consider rotated “Left Turn is not allowed” sign, the number of black pixels may be greater in right part due to rotation. So such a sign can be classified as “Right Turn is not allowed” sign.

In Figure 4.18, the example for this situation is shown. In Figure 4.18(a), “Left Turn is not allowed” and rotated version is shown. If there is no rotation, this sign can be classified successfully. However, in rotated case, the sign classified as “Right Turn is not allowed” sign. In Figure 4.18(b), the half parts of the original sign is shown. In Figure 4.18(c), the half parts of the rotated sign is shown. When the sign is rotated, the distribution of the black pixels is changed so the sign is classified as “Right Turn is not allowed” sign.

(a)

(b)

Figure 4.18 : Limitations for Rotation rate



(c)

Figure 4.18 : Cont'd

4.3.3 Color Segmentation

In the ring partitioned method, the problems which may arise are caused by colour segmentation part of the method. If the colour segmentation part does not work properly, the specified gray scale image can't be formed correctly. This causes misclassification at the output stage.

For highly illuminated traffic signs, the color segmentation can't be performed correctly so ring partitioned method does not produce the desired output for these types of traffic sign images. In Figure 4.19, the colour segmentation for highly illuminated traffic signs are shown.

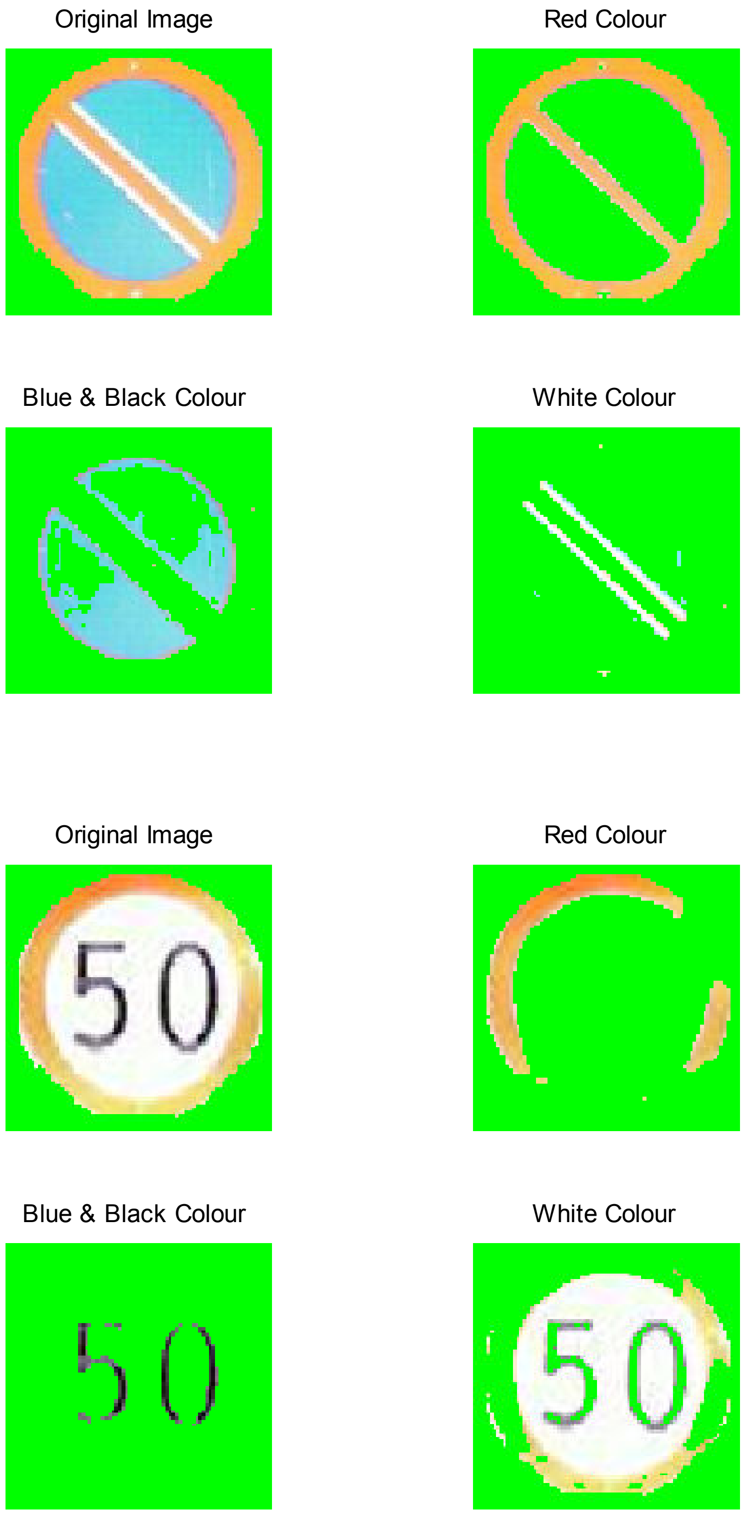


Figure 4.19 : Color Segmentation

The images in the dataset are taken in daytime so poorly illuminated are not considered. However, the shadowed images are taken into consideration in this thesis. For shadowed images, the color segmentation performs correctly and in Figure 4.20, some shadowed images in the data set are shown.

Figure 4.20 : Shadowed Images

4.3.4 Ring Partitioned Method with the Detection

The Traffic sign recognition system has two stages: detection and recognition. Firstly, the sign is extracted from traffic scene image in detection. After that the detected sign is classified in the recognition stage. The scope of this thesis just covers the recognition stage.

In experiment 1, experiment 3 and experiment 5, the input sign of the recognition stage is extracted from the traffic scene image manually. These signs can be considered as perfectly extracted signs. But the sign which is detected in the real detection stage is not perfectly extracted and it has a boundary noise. In experiment 2, experiment 4 and experiment 6, the input sign of the recognition stage is extracted from the traffic scene by using the detection algorithm. For circular signs, the Hough transform, for triangle signs, the Curvature scale spaced with dynamical threshold and for square signs, the colour based methods are used.

The recognition rate of experiment 1 is 92% and the recognition rate of experiment 2 is 91%. The results are very close. We can conclude that the ring partitioned method for circle signs is robust to detection errors.

The recognition rate of experiment 3 is 88% and the recognition rate of experiment 4 is 72%. In experiment 4, the performance of the method decreases. As mentioned before, to apply ring partitioned method to triangle signs, the corner points of the triangle must be obtained. The decrease in the performance shows that the method is very sensitive to corner points.

The recognition rate of experiment 5 is 95% and the recognition rate of experiment 6 is 90%. The results are close but we can still conclude that the ring partitioned method for square signs is robust to detection errors.

In experiment 7, the video captured image is used. The recognition rate for circle signs is 85%, the recognition rate for triangle signs is 65% and the recognition rate for square signs is 80%. The recognition rate of the ring partitioned method decreases compared to still images.

CHAPTER 5

CONCLUSIONS AND FUTURE WORKS

5.1 CONCLUSIONS

In this thesis, recognition of traffic signs is studied. The ring-partitioned method is implemented in MATLAB and this method is extended to triangle and square signs. Five different data sets containing 500 traffic signs are used for testing. These data sets contain still and video captured images.

The ring-partitioned method [39] is a histogram-based method. The input image is divided into rings and the Euclidean distance between histograms of these rings and the corresponding rings of the reference image are calculated. The sign with the minimum Euclidean distance is selected as output sign.

The advantage of rings is to provide robustness to rotation in circular signs. The rotation of circular signs is not determined in the preprocessing stage because the circular signs have no corner. Therefore, the rotation must be taken into consideration in recognition stage. In ring-partitioned method, the rotation does not affect the histogram of the ring so the rotated signs can be recognized.

In ring-partitioned method, the specified gray scale image is used to provide robustness to illumination. In gray scale image, red, black, white and blue colors are segmented. After segmentation, the histograms of these colors are transformed into pre-determined histograms by using histogram specification techniques. The output histogram of this transformation is approximately the same for different illumination conditions. To obtain histogram specification image correctly, the color segmentation must be performed perfectly. However, it is hard to find such a color segmentation method to give the perfect results for all illumination conditions. It is expected that the color segmentation part of the method cause some misclassifications. In this thesis, the images taken in daytime are considered so the color segmentation method used in this thesis gives the best result for this type of conditions. However, color segmentation errors can occur for highly illuminated images.

The ring-partitioned method is suitable for circle signs due to rings. To extend this method, the circumscribed circle of triangle and square is used. After finding the circumscribed circle, the ring partitioned method is applied to triangle and square signs like circle signs.

There are two types of images in the data sets: The perfectly extracted signs and traffic scene images. The perfectly extracted signs contain only the traffic signs and traffic scene images contain background and the traffic sign. In traffic scene images, the detection methods are used to extract the traffic sign.

In detection stage, Circular Hough transform for circular signs, Curvature Scale Space with Dynamic Threshold method for triangular signs and color-based detection for square signs are used.

The recognition rate for perfectly extracted circular signs is 92% and for detected circular signs by CHT is 91%. We can conclude that the ring-partitioned method is not affected by extraction errors.

The recognition rate for perfectly extracted triangular signs is 88% and for detected triangular signs by corner detection is 72%. The recognition rate decreases in detection stage. We can conclude that the ring-partitioned method is affected by extraction errors and is very sensitive to corner points.

The recognition rate for perfectly extracted square signs is 95% and for detected circular signs by color based detection is 90%. The recognition is very close in two cases so the ring-partitioned method is not affected by extraction errors. Square signs include certain ideograms so this makes the recognition easier.

The recognition rate for circular, triangular and square sign images decreases in video captured images. These images are more noisy than still images.

Generally, the main reason for misclassification is color segmentation. Unsuccessful classification results in wrong specified gray scale image.

5.2 FUTURE WORKS

Firstly, the image statistics for different time of the day can be determined to use the different parameters according to time. This may improve the accuracy and effectiveness of the algorithm.

In detection stage, the shape and color based detection techniques can be used. This may improve the performance of the detection process.

Increasing the number of rings used in ring-partitioned method can improve the performance of the method. The recognition algorithm can be improved by an additional stage that pre-classifies the traffic signs with respect to color feature before the recognition stage. This decreases the number of signs to be classified so the accuracy and the speed of the recognition stage can improve.

REFERENCES

1. O.M.J Carlsen, L.Nillson, Safety Assesments of Driver Assistance Systems. *European Journal of Transport and Infrastructure Research.* 2001, pp.225-243.

2. Wikipedia Advanced driver assistance systems, http://en.wikipedia.org/wiki/Advanced_Driver_Assistance_Systems, last_accessed date: 17/11/2010

3. S. R. Madeira, L. C. Bastos, A. M. Sousa, J. F. Sobral, L. P. Santos, Automatic Traffic Signs Inventory Using A Mobile Mapping System , 2005.

4. Tao, C. Vincent , Mobile Mapping Technology for Road Network Data Acquisition. *Journal of Geospatial Engineering.* pp 1-13, 1998, Vol. 2, 2.

5. “Road Sign Recognition Survey” [On line] Available: http://euler.fd.cvut.cz/research/rs2/files/skoda-rs-survey.html, last_accessed date: 23/11/2010

6. Hsiu-Ming Yang, Chao-Lin Liu, Kun-Hao Liu ,Shang-Ming Huang, Traffic Sign Recognition in Disturbing Environments. *Foundations of Intelligent Systems .* pp 252-261, 2003, Vol. 2871.

7. H. Fleyeh, *Shadow and highlight Invariant Colour Segmentation Algortihm For Traffic Signs,* IEEE International Conference on Cybernetics and Intelligent Systems, Bangkok, Thailand ,2006.

8. D. Ghica, S.W. Lu, X. Yuan, *Recognition of Traffic Signs by Artificial Neural Network*, IEEE International Conf. on Neural Networks, Perth,Australia , 1995.

9. W. G. Shadeed, D. I.Abu-Al-Nadi, M. J. Mismar, *Road Traffic Sign Detection in Color Images* , IEEE International Conference on Electronics, Circuits, and Systems, Shariqah, United Arab Emirates ,2003.

10. A. De la Escalera, L. E. Moreno, M. A. Salichs, J. M. Armigol. Road Traffic Sign Detection and Classification. *Transactions on Industrial Electronics, IEEE.* pp 848-859, 1997, Vol. 44, 6.

11. J. Hatzidimos, *Automatic Traffic Sign Recognition in Digital Images.* Thessaloniki,Greece : Proceedings of the International Conference on Theory and Applications of Mathematics and Informatics, 2004.

12. M.A. Garcia-Garrido, M.A. Sotelo, E. Martm-Gorostiza, *Fast traffic sign detection and recognition under changing lighting conditions* , IEEE Intelligent Transportation Systems Conference, Toronto,Canada ,2006.

13. E.Ulay , Color and Shape Based Traffic Sign Detection , *Middle East Technical University Msc Thesis,* November 2008.

14. İ.Özkan, Traffic sign detection using FPGA , *Middle East Technical University Msc Thesis.* 2010.

15. H. Liu, D. Liu, J. Xin, Real-time Recognition of Road Traffic Sign in Motion Image Based on Genetic Algorithm, *Machine Learning and Cybernetics Proceedings,* Vol. 1, pp 83-89, 2002

16. N. Kehtarnavaz, A. Ahmad, Traffic Sign Recognition in Noisy Outdoor Scenes, *Proceedings of the Intelligent Vehicles '95 Symposium,* pp. 460-465, 1995.

17. R. Janssen, W. Ritter, F. Stein, and S. Ott, Hybrid Approach for Traffic Sign ,Recognition *In Proc. of Intelligent Vehicles Conference,* pp 390-395, 1993.

18. N. Yabuki, Y. Matsuda, Y. Sumi, Y. Fukui, S. Miki. Active Net Control for Traffic Signs Detection, *Vehicle Electronics Conference, Proceedings of the IEEE International,* pp. 151-155, 2001.

19. Fang, Chiung-Yao, Chen, Sei-Wang and Fuh, Chiou-Shann, Road-Sign Detection and Tracking, *IEEE Transactions on Vehicular Technology.* 52, Sept. 2003.

20. L. Estevez, N. Kehtarnavaz, A Real-Time Histographic Approach to Road Sign Recognition, *Proceedings of the IEEE Southwest Symposium on Image Analysis and Interpretatio,* pp. 95-100, 1996.

21. S. EsTable, J. Schick, F. Stein, R. Janssen, R. Ott, W. Ritter, Y. J. Zheng. A Real Time Traffic Sign Recognition System. *in proc. Intelligent Vehicles'94.* 1994.

22. R. Brunelli, *Template Matching Techniques in Computer Vision: Theory and Practice,* Wiley, 2009.

23. B. Cyganek, *Road Signs Recognition by the Scale-Space Template.* Berlin Heidelberg , 2007, IbPRIA , pp. 330–337.

24. S. Zokai,G. Wolberg, Image Registration Using Log-Polar Mappings for Recovery of Large-Scale Similarity and Project, *IEEE TRANSACTIONS ON IMAGE PROCESSING,* pp 1422-1434, 2005, Vol. VOL 14, No 10.

25.http://www.cse.yorku.ca/~kosta/CompVis_Notes/gaussian_pyramid.pdf. [Online], last_accessed_date: 5/10/2010

26. V. Andrey, K.H Jo, *Automatic Detection and Recognition of Traffic Signs using Geometric Structure Analysis,* Bexco,Busan,Korea ,SICE-ICASE International Joint Conference, 2006.

27. R. Malik, J.Khurshid, S.N. Ahmad, *Road Sign Detection and Recognition using Colour Segmentation,Shape Analysis and Template Matching,* Hong Kong : Proceedings of the Sixth International Conference on Machine Learning and Cybernetics, 2007.

28. B.Havur, TRAFFIC SIGN RECOGNITION FOR UNMANNED VEHICLE CONTROL, *Middle East Technical University Msc Thesis,* 2006.

29. S.Marsland, *Maching Learning : An Algorithm Perspective* , CRC Press, 2008.

30. Shi, Min, Wu, Haifeng and Fleyeh, Hasan. *Support Vector Machines for Traffic Sign Recognition.* Hong Kong : International Joint Conference on Neural Networks, 2008.

31. A.Khotanzad, Y.H.Hong, *Invariant image recognition by Zernike moments,* IEEE Transactions on Pattern Analysis and Machine Intelligence, 1990.

32. V.Vapnik. *Statistical Learning Theory.* New York,NY : Wiley, 1994.

33. L. Li,J. Li,J. Sun, *Traffic Sign Classification Based on Support Vector Machines and Tchebichef Moments,* Wuhan International Conference on Computational Intelligence and Software Engineering, 2009.

34. H. Ishida, T. Takahashi, I.Ide, Y. Mekada, and H. Murase, Identification of degraded traffic sign symbols by a generative learning method, *ICPR '06 Proceedings of the 18th International Conference on Pattern Recognition ,* 2006, Vol. 1.

35. C.L Huang, S. H. Hsu, *Road sign detection and recognition using matching pursuit method,* Austin, Texas , 4th IEEE Southwest Symposium on Image Analysis and Interpretation, 2004.

36. J.T Oh, H.W. Kwak, Y.H. Sohn ,W:H Kim, *Segmentation and Recognition of Traffic Signs Using Shape Information,* Berlin Heidelberg ,Springer-Verlag, 2005.

37. J. Huang, S. R. Kumar, M. Mitra, W. j. Zhu, , Zabih, *Spatial Color Indexing and Applications* , Internatioınal Journal of Computer Vision, 1999.

38. H.Irmak, Real-time Traffic Sign Recognition System On Fpga, *Middle East Technical University MSc Thesis,* 2010.

39. A. SOETEDJO, K. YAMADA, *Traffic Sign Classification Using Ring Partitioned Method,* 2005, IEICE TRANS FUNDAMENTALS, VOL.E88-A, pp. 2419-2426.

40. R.C. Gonzalez, *Digital Image Processing,* Prentice Hall, 2008.
41. M.Benallal, J. Meunier, *Real-time color segmentation of road signs,* Montreal : CCECE-CCGEI/IEEE, 2003.
43. *Wikipedia* Circumscribed_circle, [Online] Available: http://en.wikipedia.org/wiki/Circumscribed_circle, last_accessed_date: 22/10/2010
44. D. Dubois, H.Prade, *Fuzzy sets and Systems:Theory and Applications,* New York Academic, 1980.
45. R.Zhang , M.Zhang, *A Clustering Based Approach to Efficient Image Retrieval*, Proc. Of the 14th IEEE International Conf. on Tool with Artificial Intelligence, Washington DC,US ,2002.
46. F. Mokhtarian, F.Mohanna, *Enhancing the curvature scale space corner detector,* Proc. Scandinavian Conf. on Image Analysis, Norway,2001.
47. F. Mokhtarian, R.Suomela, Robust Image Corner Detection through curvature scale space, *IEEE Trans on Pattern Analysis and Machine Intelligence,* Vol. 20, pp 1376 - 1381 , 1998
48. J. F. Canny, A computational Approach to Edge Detection, *IEEE Trans. Pattern Analysis and Machine Intelligence,* , Vol. 8, pp.679-698, 1986
49. X.C He, N.H.C. Yung , *Curvature Scale Space Corner Detector with Adaptive Threshold and Dynamic Region of Support* ,Proceedings of the 17th International Conference on Pattern Recognition (ICPR), Wien,Austria , 2004.
50. S. J. K. Pedersen, "Circular Hough Transform", [On line] Available: http://www.cvmt.dk/education/teaching/e07/MED3/IP/Simon_Pedersen_CircularHoughTransform.pdf, last_accessed_date: 9/11/2010