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REPUBLIC OF TURKEY

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TRAFFIC SIGNALING CONTROL AT HIGHWAY INTERSECTIONS USING MORPHOLOGICAL IMAGE PROCESSING TECHNIQUE

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KAMARAN HUSSEIN KHDIR MANGURI

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Traffic Signaling Control at Highway Intersections Using Morphological Image Processing Technique

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Hasan Kalyoncu University

Supervisor

Prof. Dr. Celal KORAŞLI

by

Kamaran Hussein Khdir MANGURI

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Name of the student: Kamaran Hussein Khdir MANGURI

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Prof. Dr. Mehmet KARPUZCU
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Celal KORAŞLI
Head of Department

This is to certify that we have read this thesis and that in our consensus/majority opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Prof. Dr. Celal KORAŞLI
Supervisor

Examining Committee Members	Signature
Prof. Dr. Celal KORAŞLI	…………………..
Assoc. Prof. Dr. Fatih HASOĞLU	…………………..
Asst. Prof. Dr. Taner INCE	…………………..

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Kamaran Hussein Khdir MANGURI

Signature

ABSTRACT

Nowadays, the result of growing population in intercity areas vehicle traffic congestions become an important issue to be solved. For the solution of this problem various methods and techniques have been suggested in many recent studies. Any preventive measure to ease traffic flow along the roads is valuable to save time and fuel wastage, and also reducing CO and CO_2 emissions.

In this thesis, we attempt to implement the morphological image processing technique on the images obtained from a simulated junction model. The comparisons of different images are made from the matching score results to decide green light signaling duration for each road of the junction.

During implementation of the morphological image processing technique we focus on the individual effect of each operator to improve the accuracy of matching scores. Since we are basically interested in the area occupied by the vehicles, it is observed that ignoring edge detection operator does not produce any loss in the image quality, but rather increases the accuracy of image matching scores resulted from long vehicles, daylight and seasonal variations.

The results indicate that data of matching scores for each road provides a successful decision for the green signaling duration at different daytime periods. The method suffers from vehicles having dark colors, since they are accounted as a part of the road.

Suggested future work involves the implementation of the procedure for live traffic at a junction and eliminating the problem resulted from colored vehicles under different weather conditions.

Key words: Image Processing, Mathematical Morphology, Image Matching Scores, and Green Signaling Duration.

ÖZET

Şehirlerin artmakta olan nüfusları ve buna paralel olarak şehir içi trafik yoğunluğu günümüzde çözülmesi gereken sosyal bir sorundur.. Yol kavşaklarında trafik akışını kolaylaştıran herhangi önleyici bir tedbir zaman ve petrol israfını önleme adına değerli olacaktır. Yapılan son çalışmalarda bu sorunun çözümü için yöntemler ve uygulamalar önerilmiştir

Bu çalışmada simülasyonu yapılan bir kavşak modelinden elde edilen görüntüler üzerinde morfolojik görüntü işleme yöntemi kullanılarak elde edilen sonuçların değerlendirilmesi yapılmıştır. Çeşitli görüntülerin karşılaştırılarak bir kavşakta ki herhangi bir yol için yeşil ışıl süresinin ayarlanması elde edilen eşleşme katsayısı (matching score) sonuçlarının ve morfolojik görüntü işleme operatörlerin her birinin eşleşme katsayının düzeltilmesindeki rolü değerlendirilerek yapılmıştır.

Bir kavşakta yer alan bir yol için elde edilen eşleşme katsayıları sonuçları günün değişik dönemlerinde ki yeşil ışık süresinin ayarlanmasında başarılı olarak kullanılmıştır. Ayrıca araçların işgal ettikleri alanların değerlendirilmesi dikkate alındığında kenar izleme operatörünün ihmal edilmesinin görüntü kalitesini artırmada önemli bir etkisinin olmadığı ve uzun araçlardan günlük ve mevsimsel farklılıklardan kaynaklanan görüntü değişimlerinin eşleşme katsayılarının düzeltmede etkisi tespit olduğu edilmiştir.

Önerilen yöntem koyu renkli araçların yol rengine yakın olması nedeniyle bazı uygulamalarda hatalı sonuçlar verebilmektedir.

Anahtar Kelimeler: Image Processing, Mathematical Morphology, Image Matching Scores, and Green Signaling Duration.

To My Parents

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LIST OF SYMBOLS/ABREVIATIONS

SE	Structure Element
PCT	Principal Components Transform
EM	Electromagnetic
GOES	Multispectral Geostationary Operational Environmental
PCI	Peripheral Component Interconnect
MS	Matching Score
GLD	Green Light Duration
TG	Green Light Time Duration
OCR	Optical Character Recognition

CHAPTER 1

INTRODUCTION

Due to growing populations, the usage of cars through intercity areas is increasing day by day. This growth has nonlinear property; especially in cities with developing infrastructure widening roads, intersection and bridges enhances this nonlinearity. Therefore, any afford for improving traffic control system is an important issue for highway traffic safety [1, 2, 3]. Heavy traffic congestions at crossroads cause time wastage, high fuel cost and other environmental concerns such as increasing CO_2 and CO emission in the atmosphere [4]. At the same time it is necessary to design a system to avoid the casualties thus preventing accidents, collisions, and traffic jams at junctions [5]. In this respect image processing is found [6] to produce applicable results for real time traffic control.

1.1. Literature Review

To improve traffic control systems scientists and researchers applies image processing techniques based on extracting data from congestive parts of highways. Usage of image processing techniques in this respect for controlling traffic flows is found to provide valuable information for finding vehicles density on roads or highways, counting vehicles, speed measurement, vehicle classification, road monitoring, autonomous vehicle guidance, and highway state assessment such as accidents and congestion.

V. Parthasarathi, M. Surya, B. Akshay, K. Murali Siva and Shriram K. Vasudevan [5] used image processing technique to determine vehicles density by comparing and subtracting current frame and the background frame after converting the data to gray scale. They removed additional noises when converted to binary image by morphological operators such as dilation and erosion, and used image segmentation based on color to detecting ambulance and fire brigade at the end of step to achieve vehicles counted these sets of connecting pixels are labeled and marked with a bounding box.

In their paper, Nikita Sankhe, Poonam Sonar, and Deven Patel [7] focused on some applications of image processing for automatic of lane finding based on color based segmentation, and texture based segmentation for lane region detection. Also they have some descriptions about feature detection and feature aggregation when these two levels involves of processing in feature-driven approach. For object detection, they considered some fundamental issues to isolate object from the background on a single frame or a sequence frame such as thresholding, edge-based detection, and background frame differencing.

Another method was proposed by Pejman Niksaz [8] for analyzing image data for traffic congestion. The method follows two phases for detection. In the first phase, images were captured by camera and then, RGB to Grayscale conversion were performed. In the second phase, Gamma correction for image enhancement was used to analyze vehicle tracking. The method uses object definition based on object contour extraction and then vehicle tracking based on motion detection.

In the paper of Madhavi Arora and V. K. Banga [4], image processing was performed in two parts; in the first part image processing based on morphological edge detection was applied for determining the traffic density and in the second part sensors were used to count vehicles to control traffic signaling sequence with fuzzy logic technique.

Pallavi Choudekar, Sayanti Banerjee, and M. K. Muju [9] used image processing to control real time image which is based on edge detection. Edge detection technique was applied to detect the abrupt changes in the gray level of the image, and then the outcome was processed to determine the percentage of matching between reference and real time images.

In a similar attempt Naeem Abbas, Muhammad Tayyab, and M.Tahir Qadri [10] applied image processing technique to count density of traffic. Their work was performed in three phases. In the first phase, the image acquired from a fixed camera was processed by image cropping technique to select presence of vehicles in target area. In the second phase image enhancement was done by object detection or vehicle detection. Finally, in the last phase vehicles were counted by applying the algorithm which searches for connected pixel and marked connected regions in order to determine degree of traffic density.

Kavya P Walad and Jyothi Shetty [11] employed edge detection image processing techniques to control traffic density at a cross road. They showed that edge detection is important characteristic of image. Also, they discussed different types of edge detection techniques and compared their advantages and disadvantages.

Mohammad Shahab Uddin, Ayon Kumar Das, and Md. Abu Taleb [12] applied image processing to estimate traffic density along roads. They employed both Canny edge detection and image dilation method to extract vehicle edges, since a road having greater area vehicle edges was considered to cause more traffic congestion than the normal.

1.2. Proposed Work

The proposed work describes a method to control vehicle density to predetermine traffic density at a junction, hence the timing to be allowed green signaling for each road of a junction. The method is based on morphological image processing techniques [4], which allows real time traffic control at junctions on highways. Data to be processed is obtained from a simulated model of a junction with four cameras located in the direction of the each road, and the acquired data is used to analyze traffic flow, vehicle speed, counting vehicles, accident investigation, and traffic congestion hence. The results are thought to help to determine the traffic signal timing sequence at different time periods of a day for proper flow control.

CHAPTER 2
IMAGE BACKGROUND AND MATHEMATICAL MORPHOLOGY

Currently different types of images are used in image processing and computer vision applications. This difference makes image processing to use some methods to ease solution of image databases. Morphological image processing is one of technique which uses binary and grayscale images. In this chapter details of both image types and mathematical morphology applied for image processing are explained.

2.1. Continuous to Discrete Images

In general, a set of physical captors is used for image acquisitions [13]. The process of data acquisition can be accurately modeled for sampling of the continuous image using a discrete partitioning of the continuous space. Discrete space can be achieved from continuous space by using sampling and this process is called spatial quantization or simply digitization [14]. In these processes only three types of type of polygons are used for constructing a partition of the space [13]. The possible numbers of sides of the regular polygon are three, four and six, leading to triangular, square and hexagonal partitioning schemes. Physically, such polygons represent captor sensitivity for the intensity of light. Their output is a value on a scale. A polygon area of constant color is called a picture element or pixel, for short. Color captor outputs have three values for each pixel (e.g. RGB), while they have one values for gray scale image. Continuous and discrete samples are shown in Figure 2.1 and 2.2.

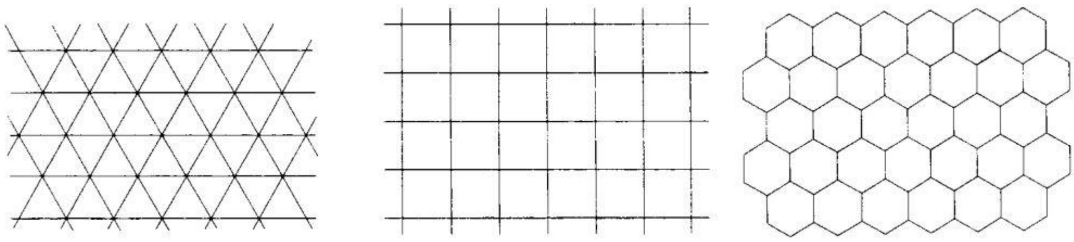


Figure 2.1 Continuous sampling scheme

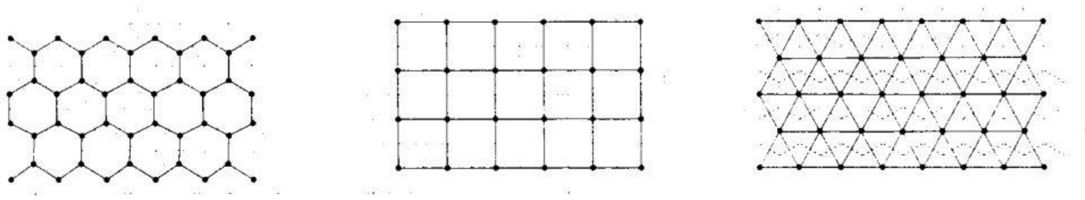
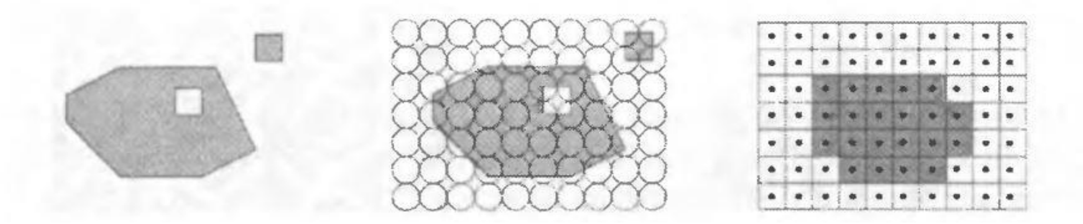


Figure 2.2 Results converted samples of Figure 2.1 to pixels

As shown in Figures 2.1 and 2.2., a lattice can be built which connects all such pixel centers. The sampling partition is represented with dotted lines and the pixel centers as black dots. The lattice represented with continuous lines is dual to the partition in the sense that two pixels are joined in the lattice if and only if the two partition polygons share a common edge [13].

Hexagonal and triangular lattices have different partitioning, where hexagonal lattice is a converted form of triangular partition i.e., triangular partitioning results from hexagonal lattice. But result of square lattice is square sampling of the image [13]. (Figure 2.2).

In the domain of spatial of the image sampling, color scale image sampled by giving number of discrete ranges (e.g. 24-bit color image), gray scale image one-dimensional color, and only two range of color black and white for binary image.



(a) A continuous object. (b) Sampling windows. (c) Resulting picture elements.

Figure 2.3 Continuous objects to pixels

Binary image results provide two-dimensional image array of pixels, where color of each pixel is associated with color value which can be either white (1) or black (0) [13].

2.1.1. Discrete Images

Discrete images are different because of the type of numerical information associated with each image pixel [14]. Both binary and gray (e.g. gray tone) images are distinguished by the range of the values given to the points or pixels of the digitization network. For binary and gray image storage single scalar values are stored for each pixel, therefore was defined as monochannel image types. In multichannel images, vector of scalar values in each pixel contains red, green, and blue. Discrete images have different formations to be explained in the following section.

2.1.1.1. Binary Images

Binary images can be used in wide range of computer vision formations because these consist of tasks for object shapes or outline information, such as grasp an object in a robotic gripper, optical character recognition (OCR), etc.. Binary image is simplest type of digital images that images have only two possible values for each pixel as either 1 or 0. Typically 1 value used for white (foreground) and 0 value used for black (background). Binary images to represent each pixel only need 1-bit per pixel, because only it takes 1 binary digit. Binary image can be obtained from gray images via threshold operation. When these pixel values greater than threshold, they turned to white ('1'), and turned to black ('0') for smaller thresholds (Figure 2.4) [15].

Figure 2.4 Binary Image

2.1.1.2. Grey-Scale Images

Gray scale image is referred to as monochrome, or one color, images (Figure 2.5). The gray scale images do not have color information only have information on brightness. Level of brightness in this type of image determines number of bit in each pixel. Since 1 value is used for each pixel, therefore typically image contains 8-bit per pixel which allows having (0-255) level of brightness (gray) in each pixel [15].

Figure 2.5 Gray-Scale Image

2.1.1.3. Color Image

Color image can be modeled as three band monochrome image data, where each band of the data corresponds to a different color. The brightness information stored in the digital image data for each spectral band. Image is displayed on screen based brightness information at pixels (picture elements) when emitted light energy corresponds to particular color. Typically color image represented by these are red, green, and blue (or RGB images). In standard modeling, for color imaging 8-bit monochrome is used to represent each color therefore 24-bit (bpp) cover up RGB band (8-bit for each color band in RGB color set) (Figure 2.6) [15].

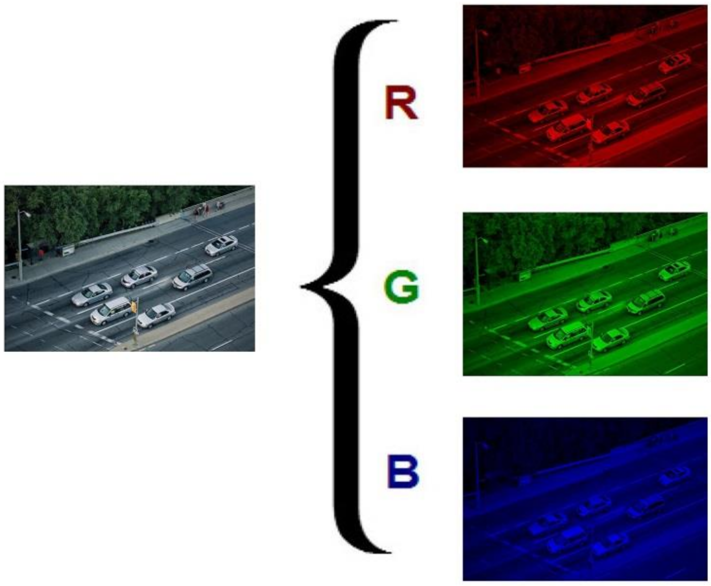


Figure 2.6 Color Image

2.1.1.4. Multispectral Images

Multispectral images are another types of images, which contain information outside the visible range of a normal person such as IR, UV, x-ray, or another band of EM. Information of these images cannot be directly represented. However, the information is often represented in visual form by mapping the different spectral bands to RGB components. Apply a principal components transform (PCT) to reduce dimensionality for these images where these have more than three bands (RGB) of information. Multispectral images have some practical applications in satellite systems (Figure 2.7), IR imaging systems, various types of airborne radar, underwater sonar systems, and medical diagnostic imaging systems [15].

Figure 2.7 Multispectral Geostationary Operational Environmental Satellite (GOES) Image of North America [15].

2.2. Mathematical Morphology

Morphological method is applied successfully in many areas like robot vision, inspection, microscopy, medical imaging, remote sensing, biology, metallurgy, and digital documents [16]. Mathematical Morphology or simply *morphology* can be defined as a theory for the analysis of spatial structures [14]. *Morphology* term in biology refers to study of form and structure for both plants and animals [16].

The image processing morphology is used to analyze the shape and form of structure. It is a mathematical operation because image analysis is based on some set theory, integral geometry, and lattice algebra. Mathematical morphology is not only set of theory but it is a powerful technique for structure analysis of images [14].

In the analysis of image processing mathematical morphology refers to a branch of nonlinear algebraic operators system because it can be used in extracting regions, shapes or boundaries [1, 4]. These properties of mathematical morphology make it to be applied in a wide range of image processing such as enhancement, segmentation, compression, edge detection, restoration, texture analysis, feature generation, skeletonization, curve filling, particle analysis, shape analysis, component analysis, and general thinning [16].

2.2.1. Origin of Mathematical Morphology

Georges Matheron and Jean Serra [16] developed a geometric structure of an image in binary form, hence a set of formalism is defined to analyze the image [14]. Indeed, one may consider the matrix as the set of object points representing an image in binary codes and the pores as the complement of this set. As a consequence, image objects can be processed with simple operations such as unions, intersections, complementation, and translations [14]. Matheron has been successfully investigated the relationship between geometry of porous media and their permeability [17] and proposed the first morphological transformations for investigating the geometry of the objects coded in binary [14], therefore he is known as a leader of Mathematical Morphology [17].

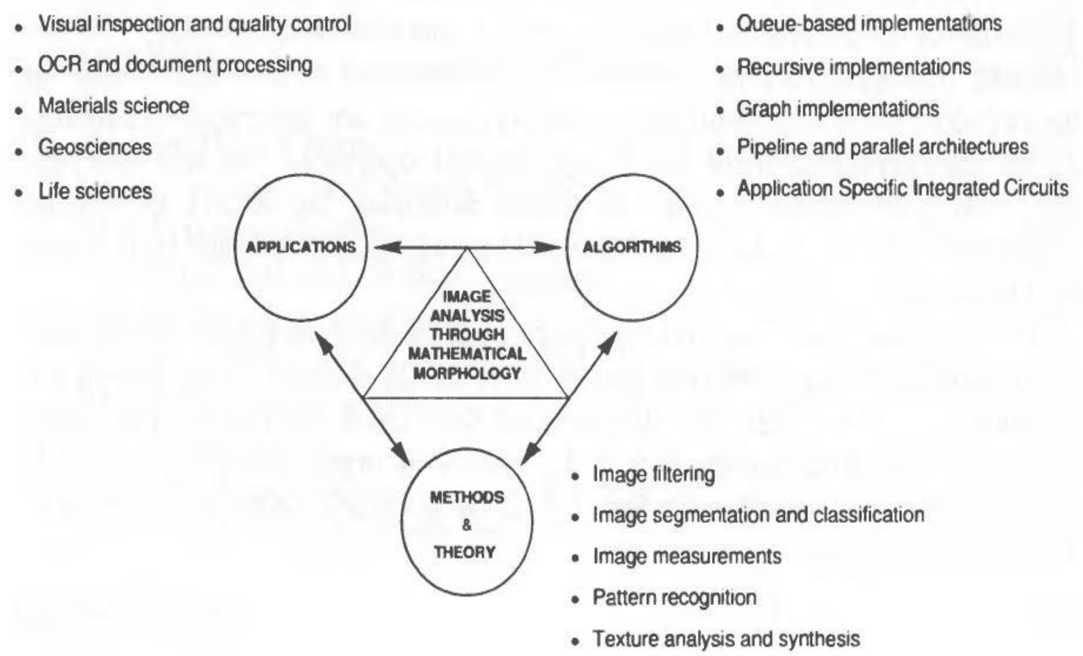


Figure 2.8 The development of mathematical morphology is characterized by a cross-fertilization between applications, theory & methods, and algorithms.

2.2.2. Morphological Operators

Aim of implementing morphological operators in any image processing is to extract image components, and it is applied to remove imperfections of images when the image is probed with another set called *structure element* [14]. The shape of structure element can be chosen based on some prior knowledge about the geometry of the relevant and irrelevant image structures [16]. There are some of morphological operations such as erosion, dilation, opening and closing to create an output image of the same size of input image after applying structure elements on an input image [18].

2.2.2.1. Preliminaries of Morphological Operators

As was explained in Section (2.2) mathematical morphology is a set theory. Sets represent objects of an image. For instance, white pixels of a binary image are morphological description of the image.

In binary images, the sets are members of the 2D integer space Z^2, where each element of a set is a tuple (2D vector) whose coordinates are the (x, y) coordinates of a white (or black) pixel in the image.

Let A and B be set (Figure 2.9 (a)), if a is the index of a pixel in A, then we written $a \in A$. If a is not in A we write $a \notin A$. If every element that is in A is also in B then A is a subset of B, written $A \subseteq B$, and equivalent statement written by $a \in A \Rightarrow a \in B$ [19].

A. Union: A union of sets A and B that means collecting elements of A and B in one set (Figure 2.9 (b)).

B. Intersection: The intersection of two points of the sets A and B produce point elements contained in both A and B. It is possible that the sets A and B have no common elements in this case. The sets are called disjointed (Figure 2.9(c)).

Intersection is written by

$$D = A \cap B = \{p | p \in A \text{ } and \text{ } p \in B\} .$$

Disjoint or mutually exclusive is written by ($A \cap B = \emptyset$), where $\emptyset$ indicates empty set.

C. Complement: The set of elements that are not contained in A called complement A^c (Figure 2.9(d)). $A^c = \{\omega | \omega \notin A\}$.

D. Difference: The difference between A and B is the set in A not intersected with B (or do not have in set B) (Figure 2.9(e)).

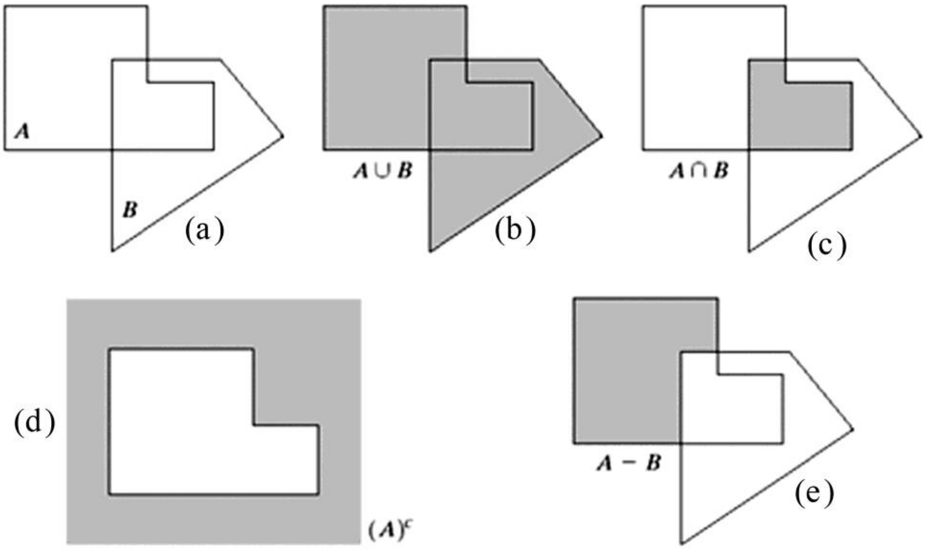


Figure 2.9 Set operations

E. Translation: The translation of set B by point $z = (z_1,z_2)$,denoted as $(B)_z$, is defined as:

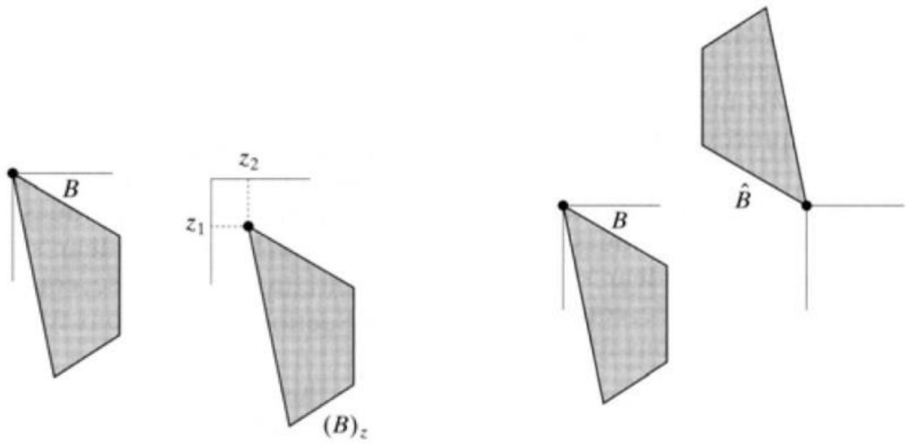
$$(B)_z = \{c | c = b + z, for\ b \in B\}$$

If B is the set of pixels, $(B)_z$ is the set of points, whose coordinates (x, y) were replaced by $(x+z_1, y+z_2)$ (Figure 2.10(a)).

F. Reflection: The reflection of set B denoted by $\hat{B}$ and defined by:

$$\hat{B} = \{w | w = -b, for\ b \in B\}$$

If B is a set of pixels (2D points) representing an object in an image, then its reflection is the set of points in B, whose (x, y) coordinates have been replaced by $(-x, -y)$ (Figure 2.10(b)).



(a) Translation (b) Reflection

Figure 2.10 Translation and reflection. Origin identified by dot

2.2.2.2. Structuring Element

Structuring element is a small set of sub images or shapes used to probing images and can be used to investigate the morphology of n-dimensional image objects. The shape of structure element is dependent on geometry knowledge of the image [14]. Morphological operators produced by the interaction a set of pixels of interest in the image with structuring element. The structuring element has both a shape and an origin [19]. There are two types of structuring element: Flat Structuring Element like disk, hexagon, square, line segment, diamond and pair of points (Figure 2.11) and Non-flat Structuring Element like arbitrary and ball [20].

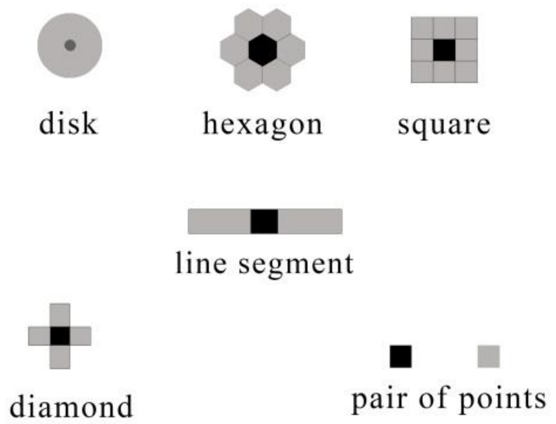


Figure 2.11 Flat Structuring Element examples

While applying interaction structuring elements with images, changing the shape of structuring element to rectangle results in the smallest number of background elements (Figure 2.12) [20].

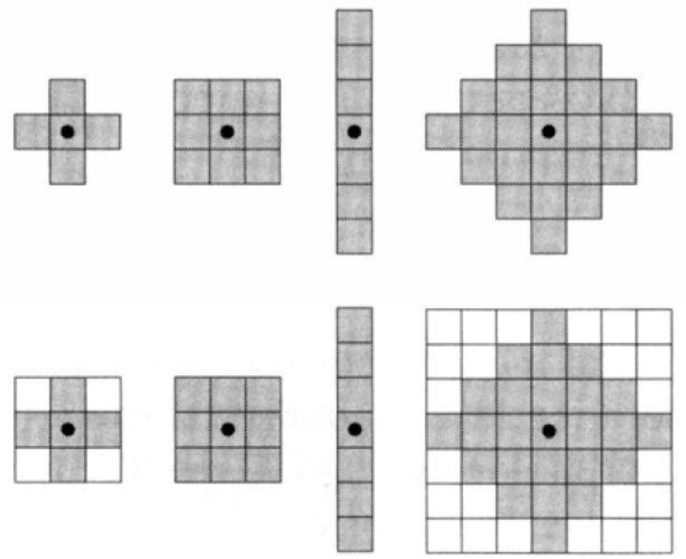


Figure 2.12 Changing shape of structure element to rectangular

In Figure 2.12, member of structuring elements are shown as shaded and origins of structuring elements are marked by a black dot.

2.2.2.3. Dilation

The dilation operation thickens, grows, or enlarges objects in a binary image. The extent of thicken is controlled by the shape and size of structuring element [21, 20]. In dilation process throughout domain of images origin of structure element is translated and reflected, and is checked to see whether it overlaps with 1-valued pixels. Dilation is used for repairing breaks and intrusions [19].

The dilation of *A* by *B*, denoted by $A \oplus B$, is defined as

$$A \oplus B = \{z \mid (\hat{B})_z \cap A \neq \emptyset\} \quad (2.1a)$$

The output image (dilation image) of *A* by the structuring element *B*, then it is the set of all displacements, *z*, such that *B* and *A* overlap by at least one element in the input image.

$$A \oplus B = \{z \mid [(\hat{B})_z \cap A] \subseteq A\} \quad (2.1b)$$

where A is input image, $\oplus$ is dilation operator symbol, B is structure element, $(\hat{B})_z$ is translating and reflecting of structure element, z is output elements, and $\emptyset$ is the empty set.

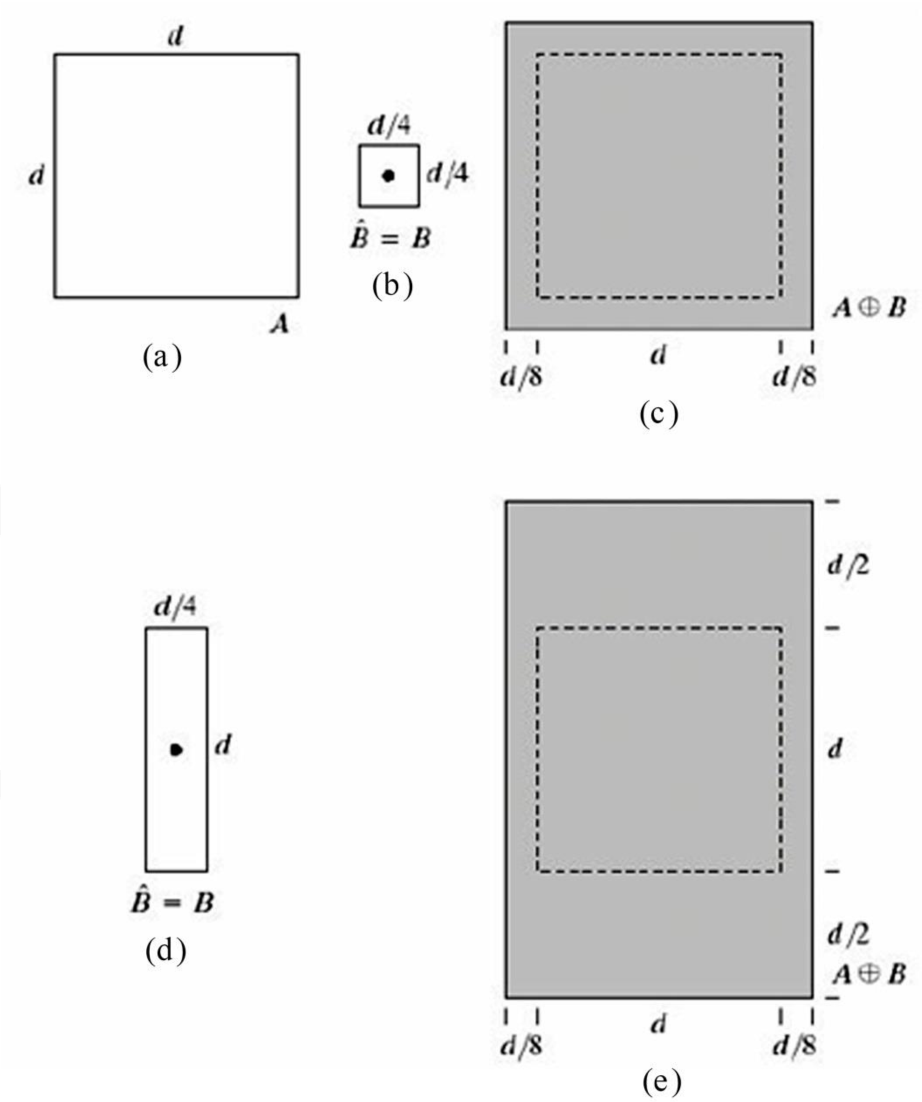


Figure 2.13 Dilation: (a) Set *A*. (b) Square structure element (dot is the center). (c) Shaded is dilation of *A* by *B*. (d) Elongated structure element. (e) Dilation of *A* by elongated structure element.

2.2.2.4. Erosion

The erosion operation makes shrinking, thinning, or removing objects in a binary image [21, 20]. The extent of shrinking or thinning is decided by the shape and size of structuring element. Erosion can split apart joined objects and can strip away extrusions [19].

The erosion has a similarity with dilation in the mathematical definition. The erosion of A by B, denoted by $A \ominus B$, is defined as

$$A \ominus B = \{z | [(B)_z \cap A^c \neq \emptyset\} \qquad (2.2 \text{ a})$$

The output image (erosion image) of A by the structuring element B then is the set such that B and A only one value overlap element in the input image.

$$A \ominus B = \{z | [(B)_z \subseteq A\} \qquad (2.2 \text{ b})$$

where A is input image, $\ominus$ is erosion symbol, B is structuring element, $(B)_z$ is translate of structuring element, A^c is complement of A, z is output elements, and $\emptyset$ is the empty set element.

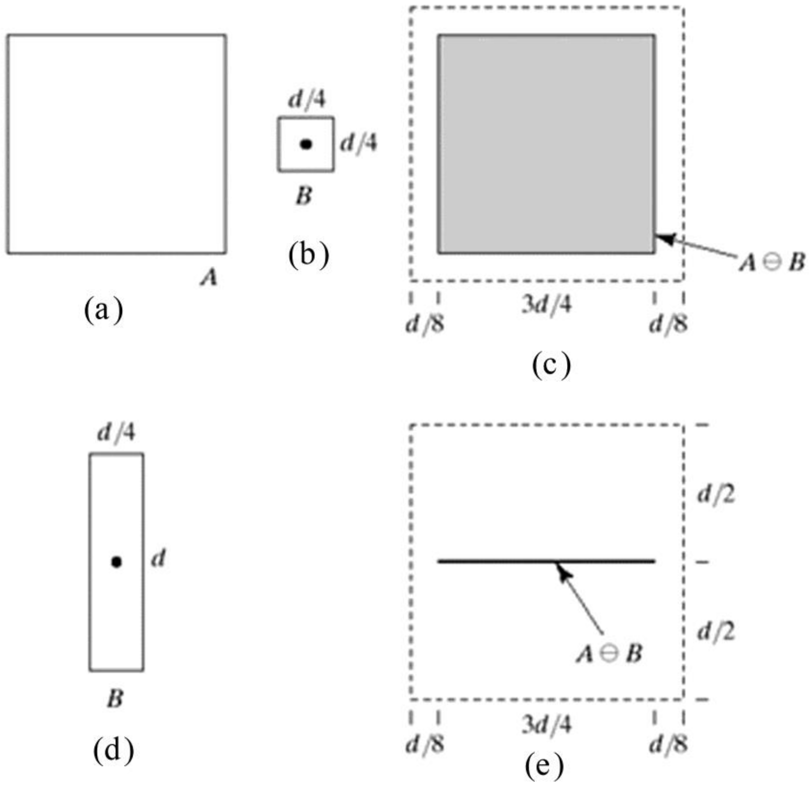


Figure 2.14 Erosion: (a) Set A. (b) Square structuring element. (c) Shaded is erosion of set A by B. (d) Elongated structuring element. (e) Erosion of A using Elongated Structure element.

2.2.2.5. Duality

Erosion and dilation are duals of each other with respect to set complementation and reflection [20]:

$$(A \ominus B)^c = A^c \oplus \hat{B} \qquad (2.3\ a)$$

$$(A \oplus B)^c = A^c \ominus \hat{B} \qquad (2.3\ b)$$

Equation (2.3b) indicates that erosion of A by B which is the complement of the dilation of the complement of A by the reflection of B and Equation (2.3b) the dilation operation complement of dilation of A by B.

Duality is particularly useful when the SE is symmetric with respect to its origin, so that $B = \hat{B}$. Then we can obtain the erosion of an image by B simply by dilating its background (complement of A) with the same structuring element and complementing the result [18]. See the Appendix A. for the proof duality principle.

2.2.2.6. Opening and Closing

Dilation and erosion are two basic operations of morphological operators; these are can be more complex sequence by combining together and most common morphological filtering when comes from combining them are *opening* and *closing* [20].

Opening: In this case erosion followed by dilation and opening can be used to smooth the contour of an object and to eliminate all pixels in regions that are too small to contain the structuring element. Structure element in opening operation called a probe because it is probing a image looking for small objects to filter out of the image [20].

Opening of set A by the structure element B is denoted by $A \circ B$ and defined as:

$$A \circ B = (A \ominus B) \oplus B \qquad (2.4)$$

Closing: In this case of closing dilation is followed by erosion and it has capability to fill in holes and small gaps.

Closing of set A by the structure element B is denoted by $A \bullet B$ and defined as:

$$A \bullet B = (A \oplus B) \ominus B \tag{2.5}$$

Differences are the results generated by closing and opening operations and both operations use dilation and erosion (Figure 2.15).

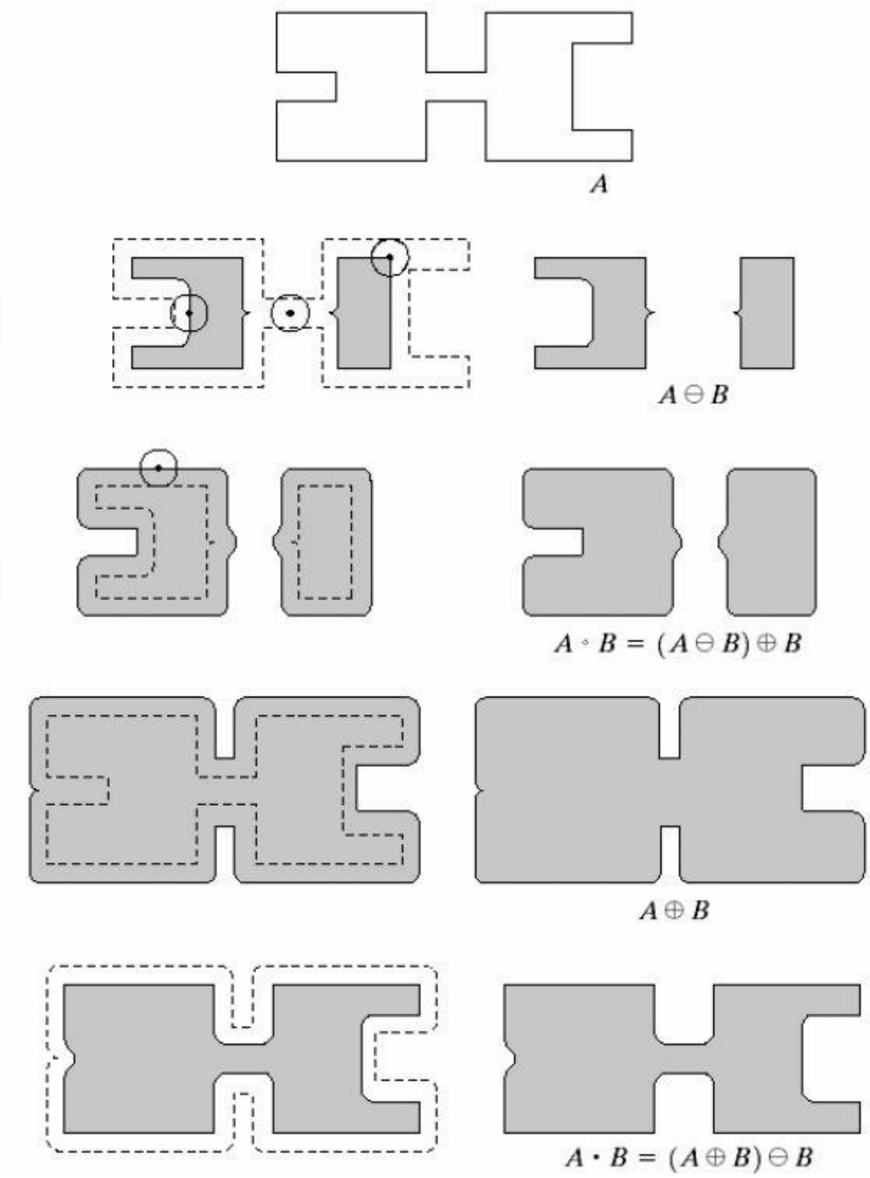


Figure 2.15 Opening and Closing: Set A, Disk Structure Element B, Erosion, Opening, Dilation, and Closing.

2.2.2.7. The Hit-or-Miss Transformation

The Hit-or-Miss Transformation one of morphological operators and can be used as the tool to shape detection and finding local pattern of pixels [19, 21]. Aim of the

Hit-or-Miss Transformation is to extract all image pixels matched by a given neighboring configuration such as a foreground pixel surrounded by background pixels e.g., an isolated foreground pixel (Figure 2.16) [14].

The Hit-or-Miss Transformation of *A* by structure element *B*, denoted by $A \otimes B$, is defined as

$$A \otimes B = (A \ominus D) \cap [A^c \ominus (W - D)] \tag{2.6}$$

The steps to be followed during Hit-or-Miss Transformation are shown in Figure 2.16.

(i) Perform union operation on the object images *C*, *D*, and *E*, which produces the set A $(i.e. A = C \cup D \cup E)$,

(ii) Subtract the object image D, (C or E) form the local background W $(i.e. (W - D))$.

(iii) Implementing complementation operation on A (A^c) (result of the step (i)).

(iv) Performing erosion operation on the results of step (i) *A* and the object image D.

(v) Performing erosion operation on the results of step (iii) A^c and step (ii) $(W - D)(i.e\ A^c \ominus (W - D))$.

(vi) Now location of D can be determined by the intersection of the results found in step (iv) and step (v) [i.e. $(A \ominus D) \cap [A^c \ominus (W - D)]$].

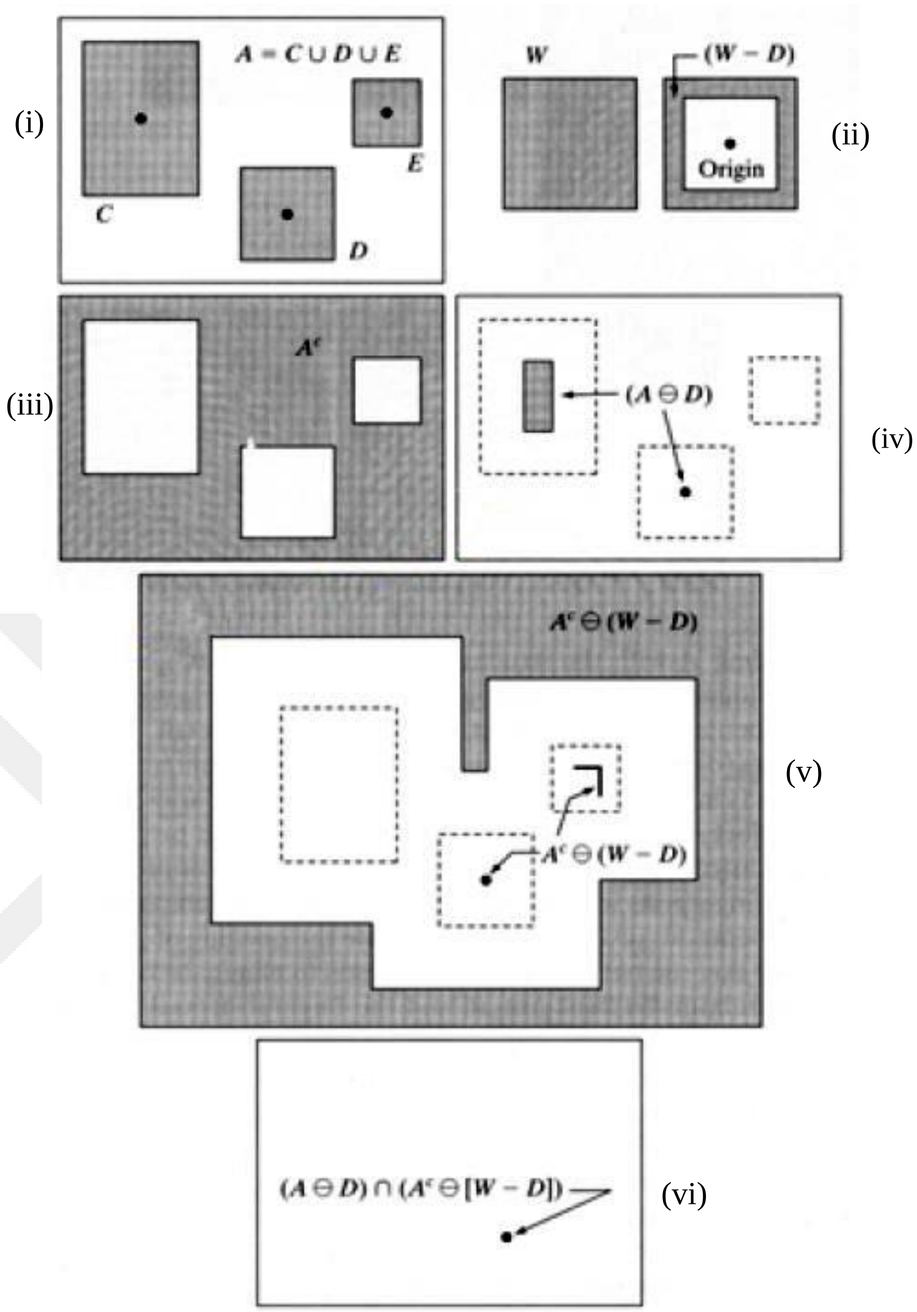


Figure 2.16 Steps followed during Hit-or-Miss Transformation

2.3. Some Basic Morphological Algorithms

Extracting image components is one of the principal applications of morphology and useful to description and representation of shapes especially when dealing with binary images; therefore we are considering some of practical uses of morphology. In particular, we consider morphological algorithms for extracting boundaries, Region filling, connected components, and the convex hull [19].

2.3.1. Boundary Extraction

The boundary of the set A can be obtained by using eroding the set A by the set B first and then finding difference between the set A and the result of erosion operation [19]. The boundary of the set A with the set of B is denoted by $\beta(A)$.

$$\beta(A) = A - (A \ominus B) \qquad (2.7)$$

where B is a suitable structuring element

'–' is the difference operation on the sets.

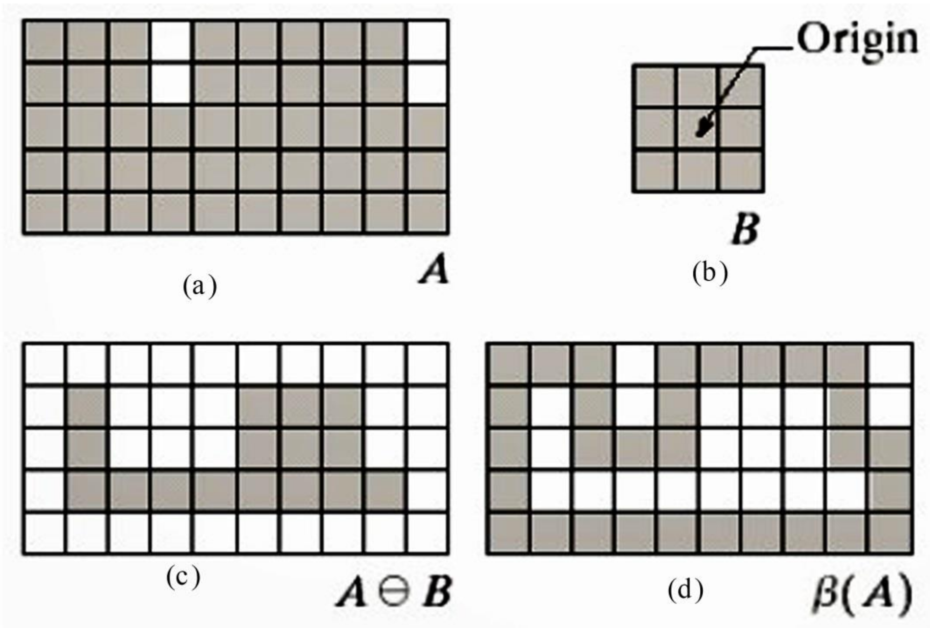


Figure 2.17 Boundary extraction example: (a) Set of A. (b) Structure element. (c) A eroded by B. (d) Boundary, given by the set difference between A and its erosion.

2.3.3. Region filling

It is another simple algorithm based on morphology to region filling that can be obtained by set dilation, complementation, and intersection. The region filling is also called hole filling [19].

$$X_k = (X_{k-1} \oplus B) \cap A^c \qquad k=1, 2, 3, \ldots \qquad (2.8)$$

where X_0 is starting point inside the boundary

B is the symmetric structuring element

∩ is the intersection operator

A^c is the complement of set A.

The algorithm terminates at iteration step k if $X_k = X_{k-1}$. The set union of X_k and A contains the filled set and its boundary.

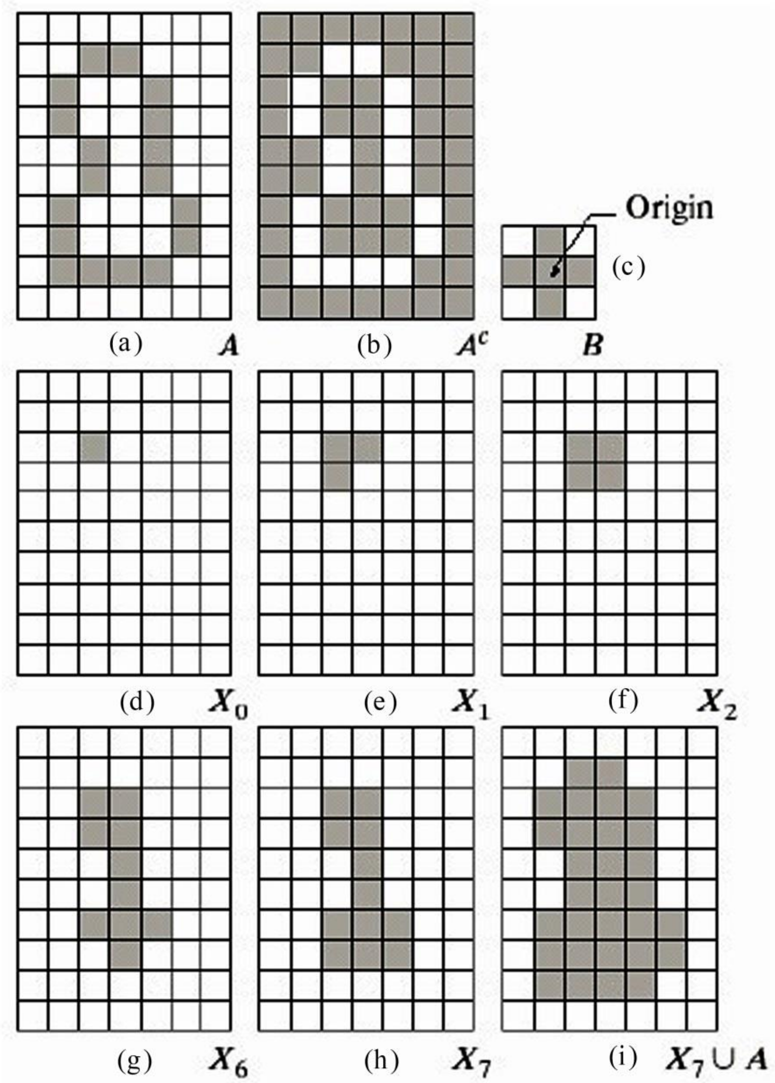


Figure 2.18 Region filling example: (a) Set of A. (b) Complement of A. (c) Structure element B. (d) initial point inside the boundary. (e)-(h) Various step of Equation. (2.8). (i) Final step [union of (a) and (h)].

2.3.3. Extraction of Connected Components

The equations of extractions of connected components and region filling are more close together with the only one difference in that A complement is not used in the extractions of connected components. After extracting the bones from the background by using a single threshold, to make sure that only objects of significant size, remain by eroding the threshold image [19].

$$X_k = (X_{k-1} \oplus B) \cap A \qquad k=1, 2, 3, \ldots \qquad (2.9)$$

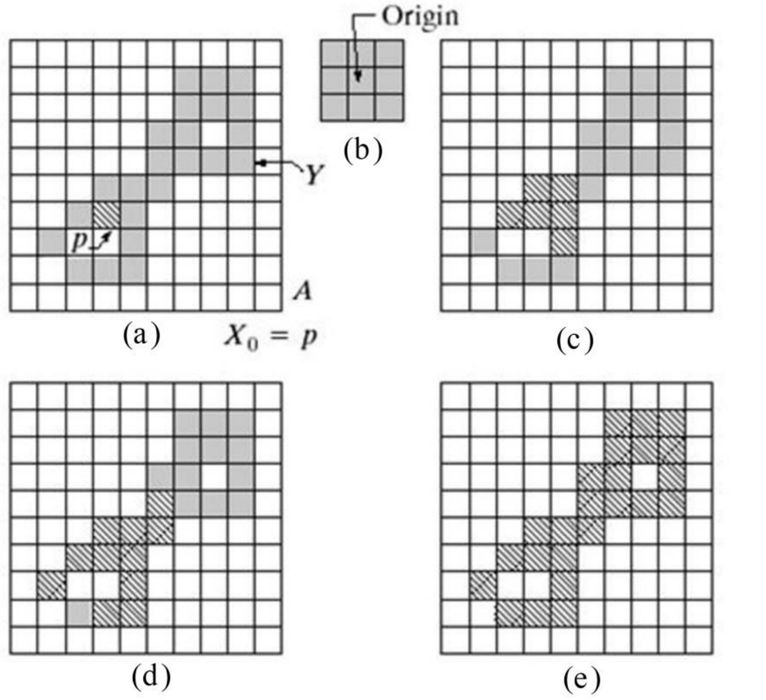


Figure 2.19 Extraction of connected components example: (a) Set A showing initial point p (all shaded points are valued 1, but are shown different from p to indicate that they have not yet been found by the algorithm). (b) Structure element. (c) Result of first iterative step. (d) Result of second step. (c) Final result.

2.3.4. Convex Hull

A is said to be convex set if the straight line segment joining any two points in *A* lies entirely within *A* [19].

$$X_k^i = (X_{k-1} \otimes B^i) \cup A \qquad i=1, 2, 3, 4 \text{ and } k=1, 2, 3, \ldots \qquad (2.10)$$

where $X_0^i = A$ and $D^i = X_{conv}^i$, ("conv"→convergence), Then the steps of convex hull operation on set *A* are shown in Figure 2.20.

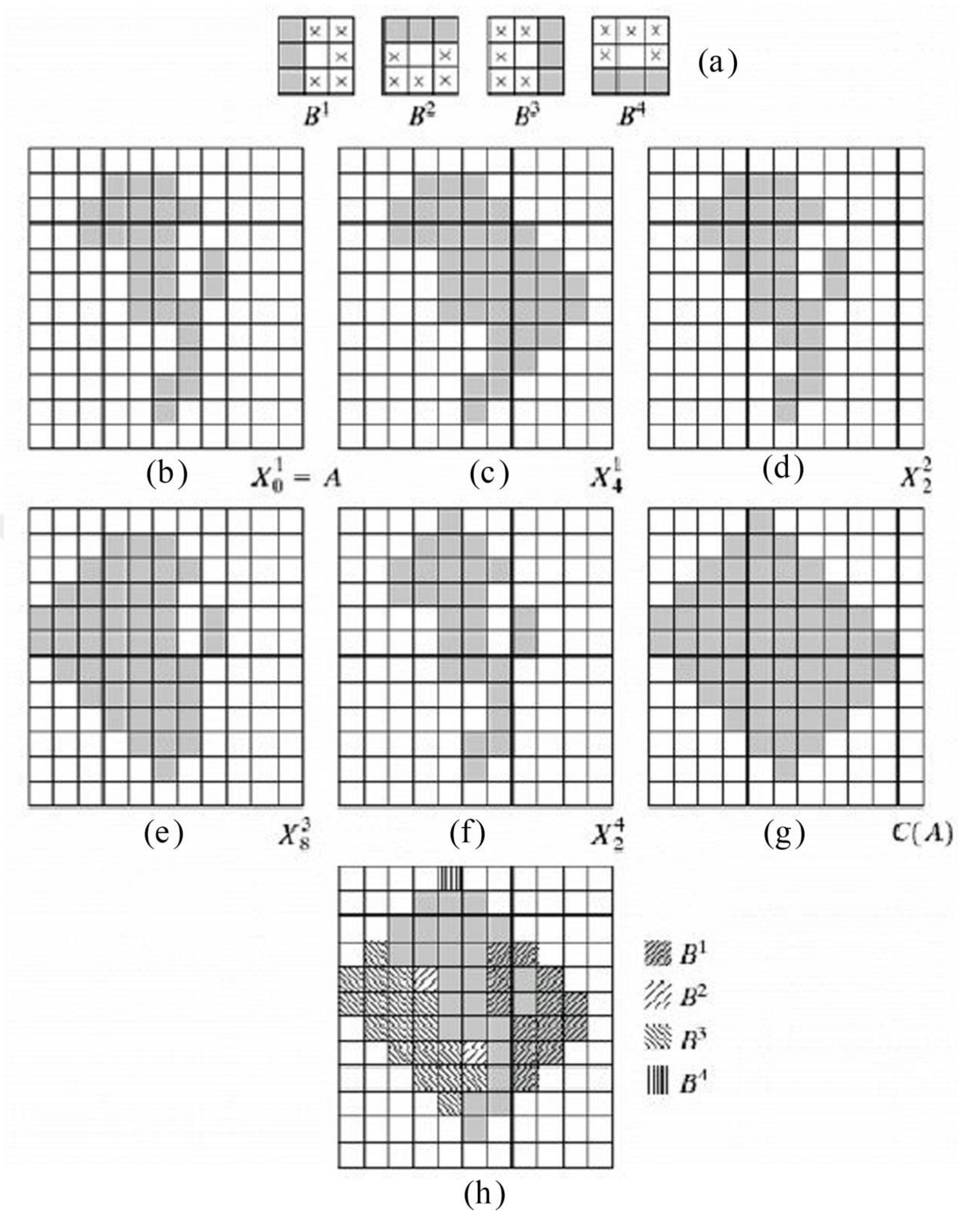


Figure 2.20 Convex Hull example: (a) Structure elements. (b) Set A. (c)-(f) Results of convergence with the structuring elements shown in (a). (g) Convex hull showing the contribution of each structure element.

CHAPTER 3

METHODOLOGY AND EXPERIMENTAL WORK

The proposed methodology based on the morphological image processing technique is explained in Chapter 2 and will be implemented in this chapter to make a possible decision for a real-time traffic control.

3.1. Applied Methodology

The morphological image processing is applied for computing traffic density at any highway junction to decide signaling time allowance for green signaling. In this work a new logic is implemented on a simulated crossroad model to increase and decrease sequentially traffic signaling. The crossroad or junction model is shown in Figure (3.1).

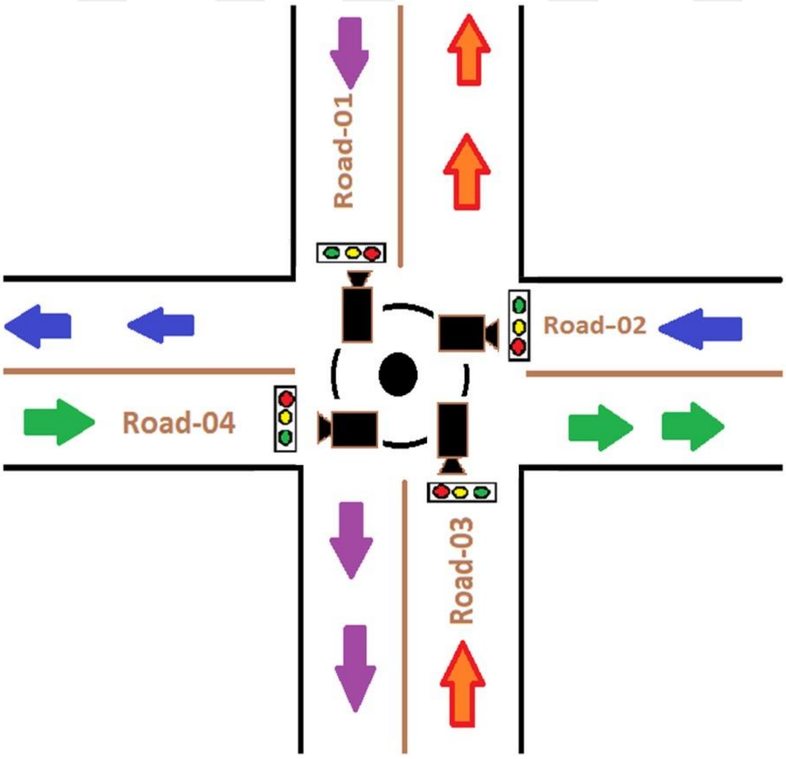


Figure 3.1 Crossroad model and cameras

The image acquisition system comprises a simulated junction model and interface units.

The cameras: These cameras are used for image data acquisition from respective road directions and linked with PCI interface units. (Appendix B)

PCI Interface- S-Link type: This hardware is used to acquire simultaneous image data from the cameras (Figure 3.2). (Appendix B)

Toy cars: These are used to simulate crossroad traffic vehicle density.

In this study morphological image processing of the image data obtained from the simulated model is carried out with image processing software (toolbox).

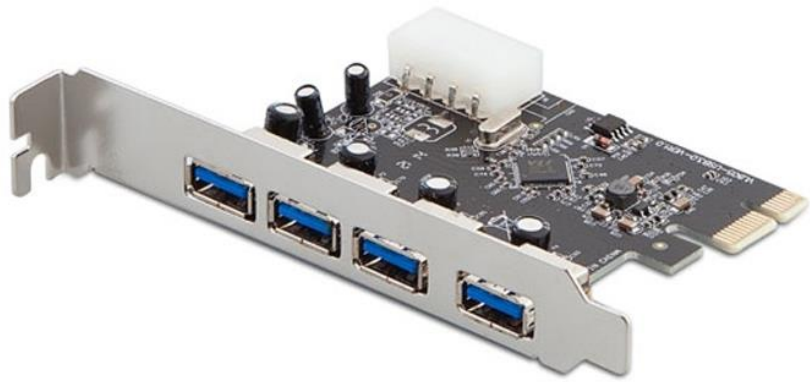


Figure 3.2 PCI Interface- S-Link type

The methodology is applied following the steps to analyze the image data of both reference (empty road) and live traffic.

3.1.1. Empty Road Image Analysis

In the proposed system image processing for an empty road follows the steps shown within blocks given in Figure 3.3:

(i) Acquisition of sequential images of the empty roads at the junction.
(ii) Resizing all captured images.
(iii) Removing unwanted parts of all images performing cropping operation.
(iv) Carrying out RGB to Binary image conversion.
(v) Applying both dilation and erosion operations (Morphological Operators) on the images.

(vi) Storing images of empty roads as reference images (as template), to compare with live traffic images, which are resulted from the operations performed through the steps given in Section 3.1.1.

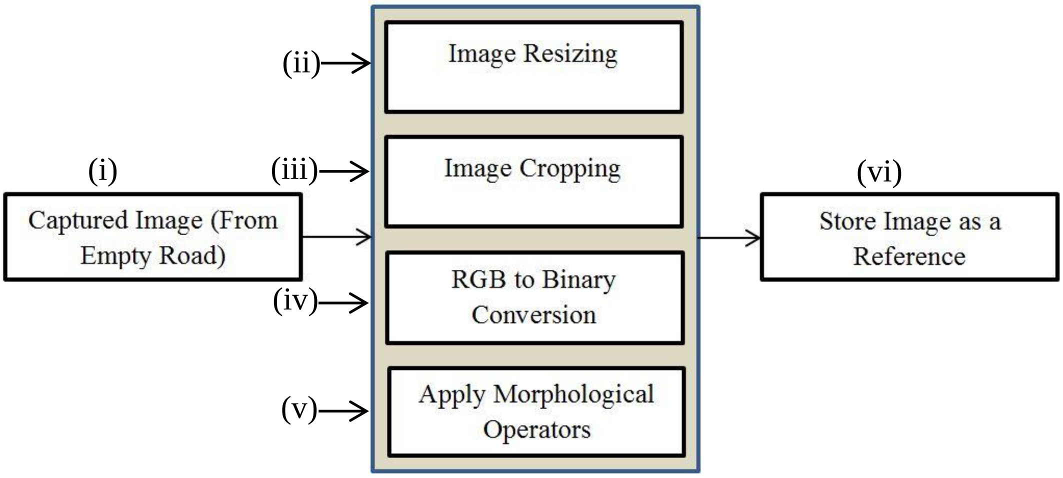


Figure 3.3 Block diagram to obtain the reference image

3.1.2. Live Traffic Image Analysis

In order to analyze live traffic images for final decision making (Section 3.1.4), the following additional steps are realized as described within the blocks of Figure 3.4.

(i) Obtain acquired sequential live images from the roads at the junction.

(ii) Resize the images.

(iii) Remove undesired parts by performing cropping operation on the images.

(iv) Perform RGB to Binary image conversion.

(v) Apply both dilation and erosion operations on the images (Morphological Operators).

(vi) Prepare the live traffic image for comparison.

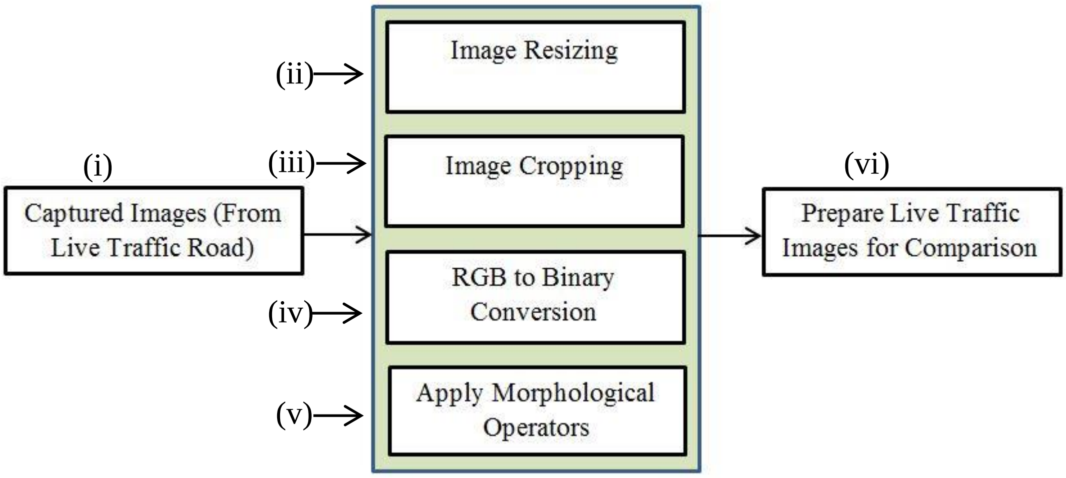


Figure 3.4 Block diagram of live traffic image

3.1.3. Matching Score

Matching scores resulted from the morphological image processing live traffic images with reference images allows us to decide whether to increase or to decrease time period for green signaling in each direction (Figure 3.3). The possible methodologies employed to compute matching score between reference image and real time image are pixel by pixel comparison, image histogram comparison, and minimum distance classifier comparison. In this work, pixel by pixel method of comparison is used to find the best matching score [22, 23], since this methodology is found to result in more accurate and faster binary images [23]. Percentage matching scores used for comparison throughout this work is defined as

$$Matching\ percentage(\%) = \frac{No.of\ pixels\ matched\ successfully}{Total\ no.of\ pixels} \qquad (3.1)$$

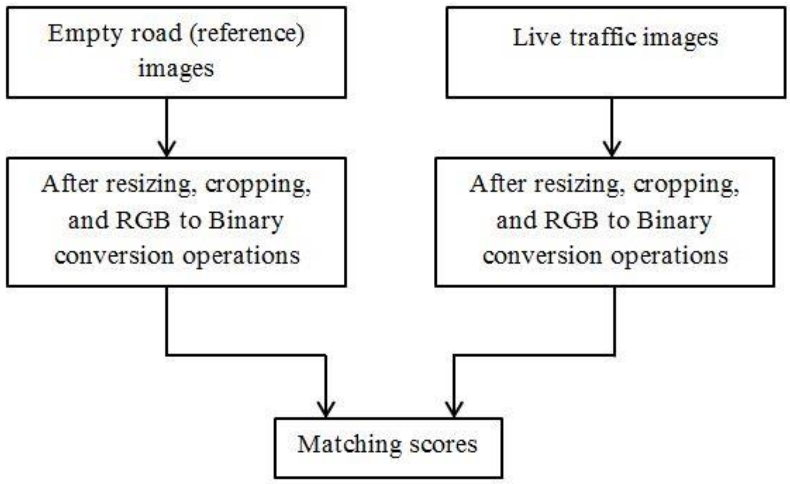


Figure 3.5 Block diagram to compute matching scores

3.1.4. Decision Making

The last stage of the methodology is matching score percentage comparison for final decision. Before applying the methodology, during normal traffic activity 30 sec time period with 5 sec (or 10 sec) allowances for green signaling will be assumed. In the literature decision for setting Green signaling duration was selected according to the matching scores results in following order [4, 24, 7, and 9].

Matching score {
- between 10 to 50% - green light on for 60 seconds
- between 50 to 70% - green light on for 30 seconds
- between 70 to 90% - green light on for 20 seconds
- between 90 to 100% - red light on for 60 seconds

In present work new logic is tested to increase and decrease a green signaling.

Matching score {
- less 15%- green light on for 40 seconds
- between 15to 40% - green light on for 35 seconds
- between 40to 60% - green light on for 30 seconds
- between 60 to 85% - green light on for 25 seconds
- above 85% - green light on for 20 seconds

The algorithm follows the steps defined according to the flowchart given in Figure 3.5. At a crossroad (junction) taking one road as a reference, in order to check matching score for green signaling the computation steps are:

1. Acquire reference and live traffic images and compute matching score (MS).
2. If MS between reference and live images is below of 15%, then allow extra 10 sec for green signaling, then go to step 7.
3. If MS between reference and live images is 15%-40%, then allow extra 5 sec for green signaling, then go to step 7.

4. If MS between reference and live images is 40%-60%, leave the normal duration of 30 sec for green signaling, then go to step 7.
5. If MS between reference and live images is 60%-85%, then decrease green signaling duration by 5 sec, then go to step 7.
6. If MS between reference and live images is above 85%, then decrease of green signaling duration by 10 sec then go to step 7.
7. Reduce green signaling duration by 1 sec (TG=TG-1).
8. If TG = 0, then go to step 7, else go to step 1

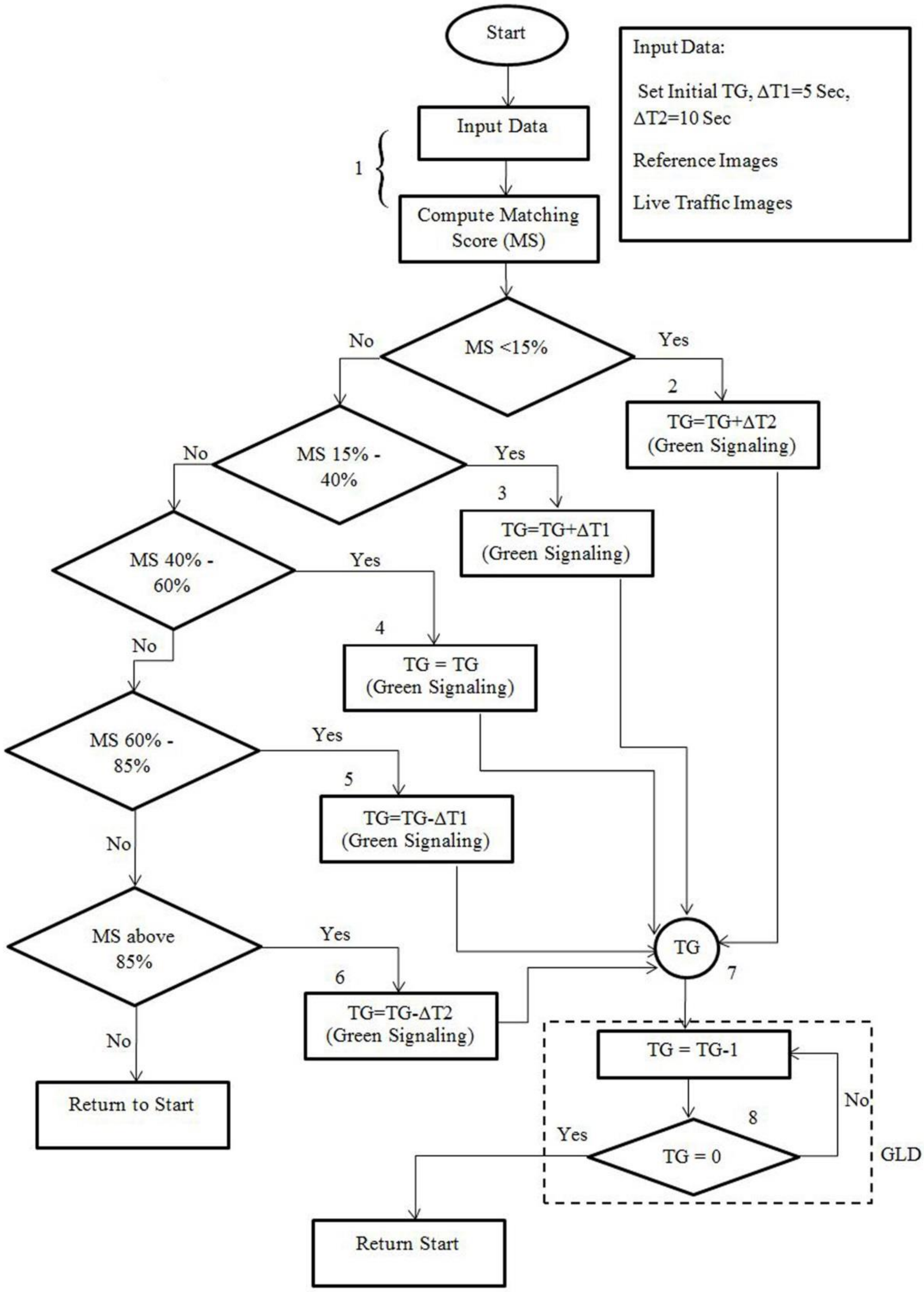


Figure 3.6 the flowchart for decision making

CHAPTER 4

IMPLEMENTATION OF PROPOSED METHODOLOGY AND ELABORATION ON THE RESULTS

The image data is obtained from the simulated crossroad model (Figure 3.1) through four cameras located in each direction. The final decision to determine green signaling duration for four roads shall be made while the image data is processed using the morphological image processing technique following the steps explained in Sections 4.1 to 4.6.

4.1. Image Acquisition

The camera images obtained from four roads in each direction while the roads are empty and converged with vehicles are shown in Figures 4.1 and 4.2 respectively.

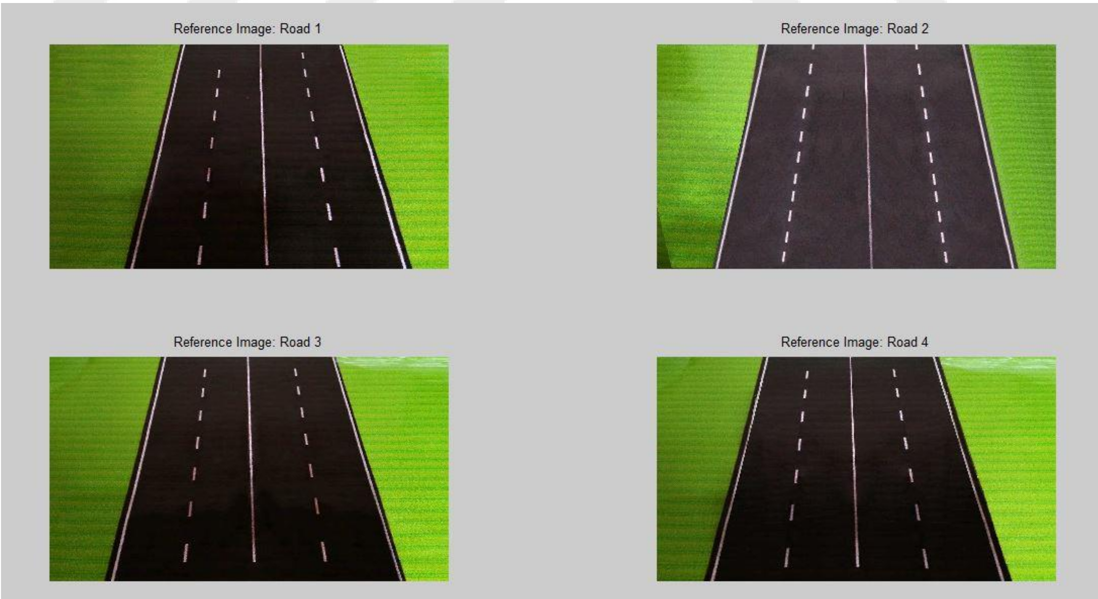


Figure 4.1 Image of empty roads

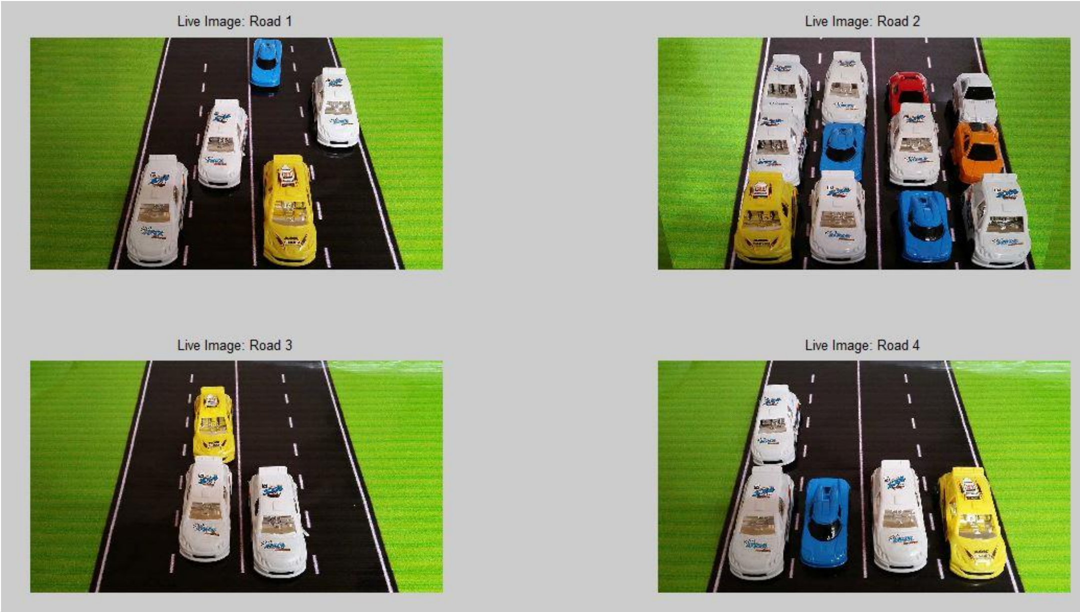


Figure 4.2 Image of roads with vehicles

4.2. Image Resizing

The methodology explained in this work is based on pixel by pixel comparison of the images, therefore binary image matching requires that the images must have the same size. Further, since the cameras have a different resolution, all the images must be resized to a prescribed pixel sizes. Resized the reference images and live road images to [800 600] pixels are shown in Figures 4.3 and 4.4, respectively.

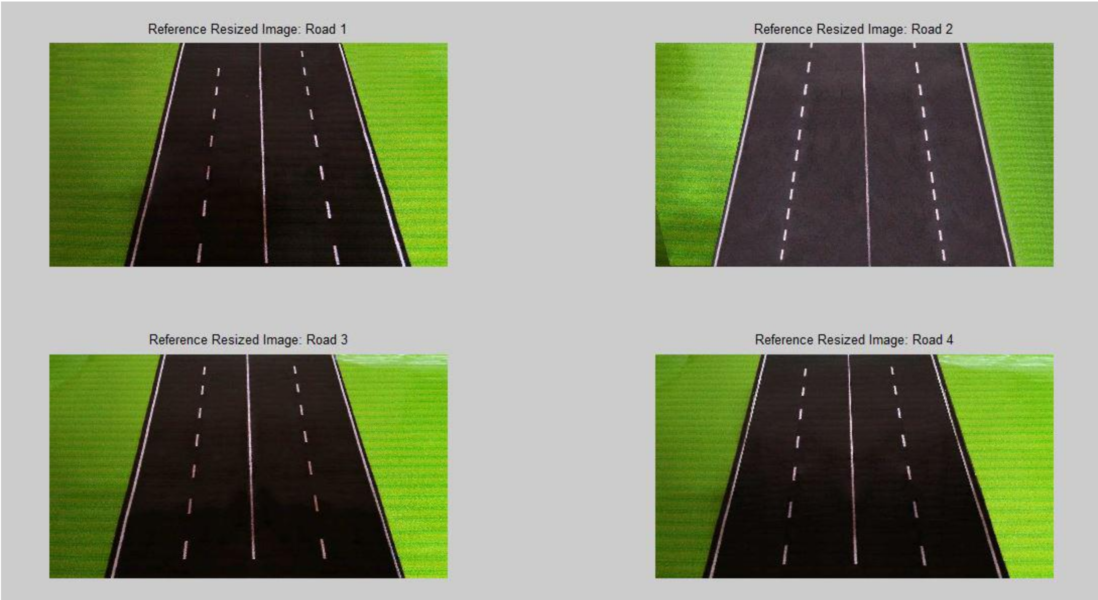


Figure 4.3 Resize reference images of empty roads

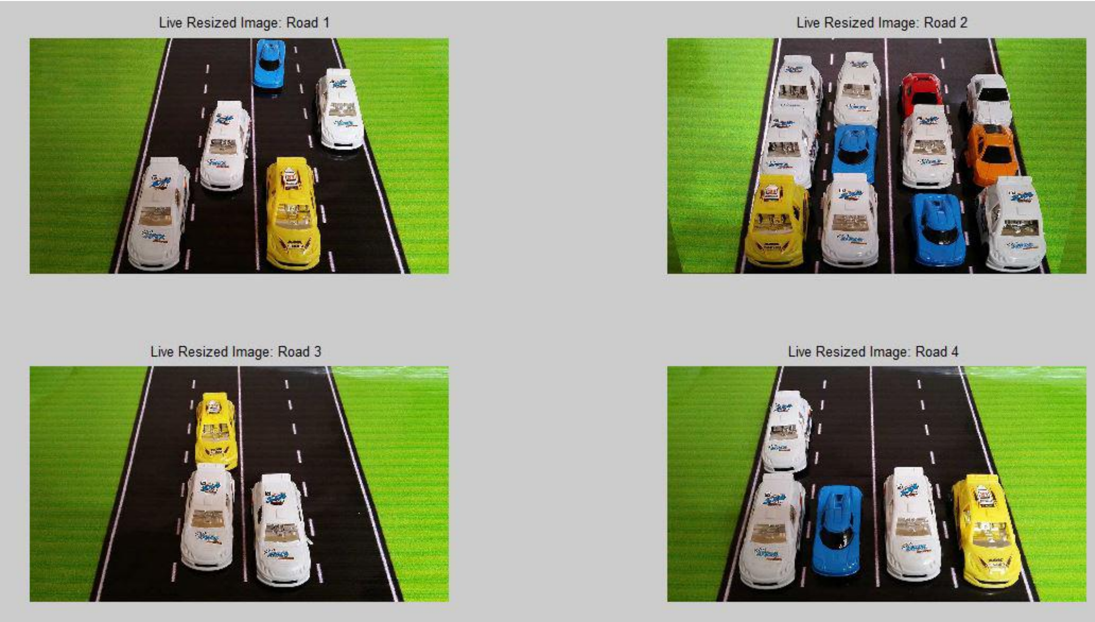


Figure 4.4 Resized live images of roads with vehicles

4.3. Cropping images

Road images shown in Figures 4.3 and 4.4 are cropped (removing irrelevant parts) according to the procedure described in Section 3.1.1 and 3.1.2. Here, notably all the undesired surrounding objects are removed from the original images. The resulting images are displayed in Figure 4.5 and 4.6.

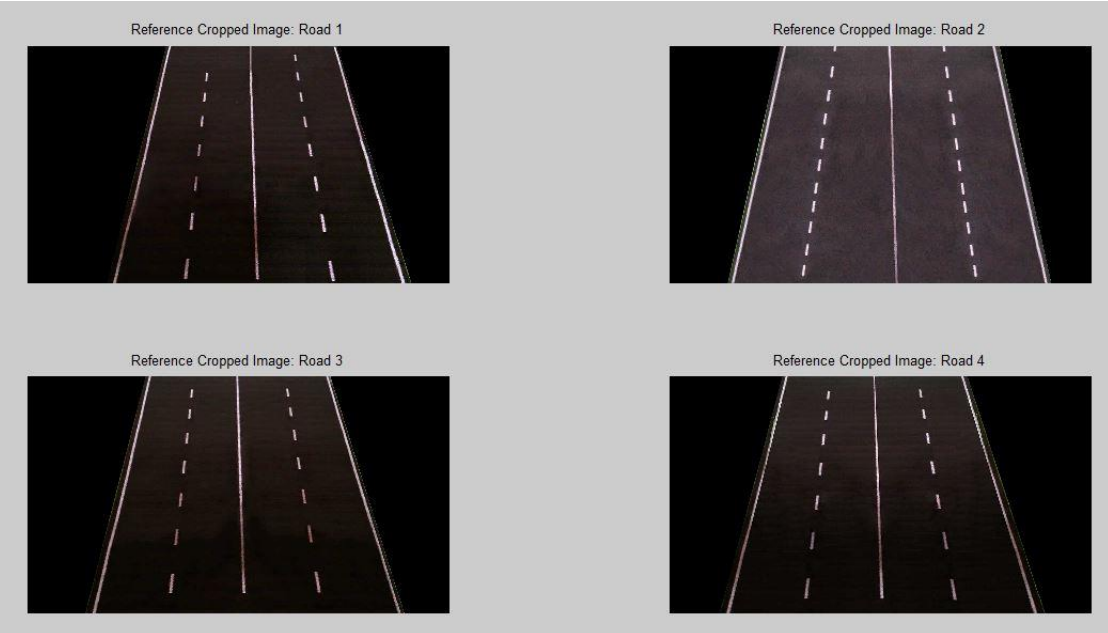


Figure 4.5 Cropping images of empty roads

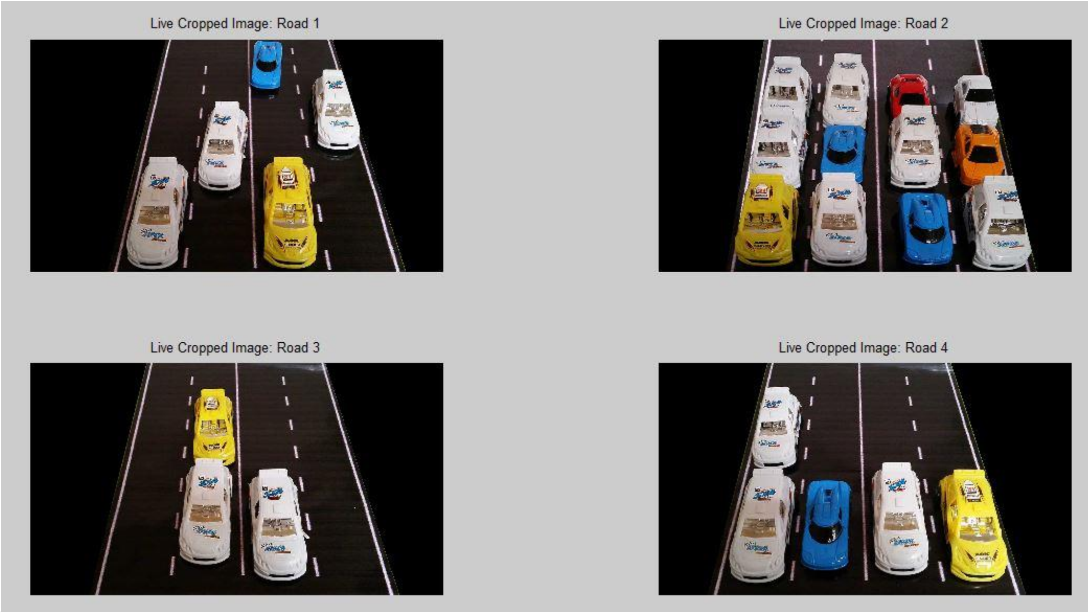


Figure 4.6 Cropping images of roads with vehicles

With this process the empty and live traffic image are freed from the extraneous road side images which make the images ready for the RGB to Binary conversion.

4.4. RGB to Binary Conversion

Morphological operators require conversion of all RGB image data to Binary image. During this process RGB colors of both reference and live road images are first converted into grayscale image, after that grayscale to binary conversion is performed using the following threshold values [25].

$$I_{result}(x,y) = \begin{cases} 0, & I(x,y) < T \\ 1, & otherwise \end{cases} \tag{4.1}$$

where T = 127 is middle value of grayscale limits(0-255), and

I_{result}(x,y) = Binary Image, and $I(x,y)$ = GrayScale Image

Figures 4.7 and 4.8 show converted form of both reference and live road images selected according to the threshold values.

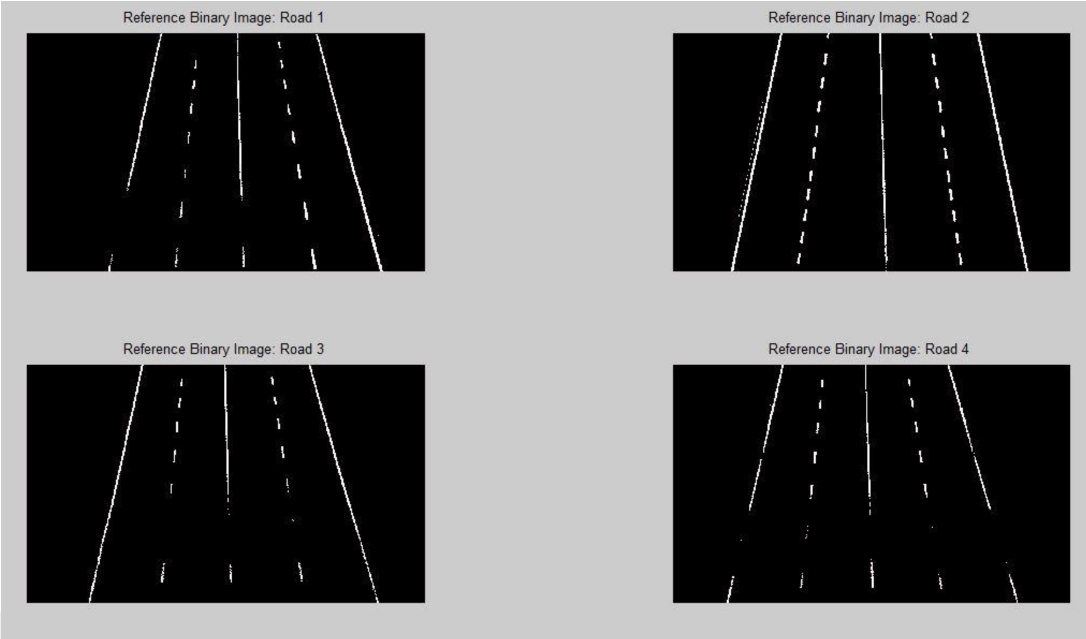


Figure 4.7 Converting reference image to binary image

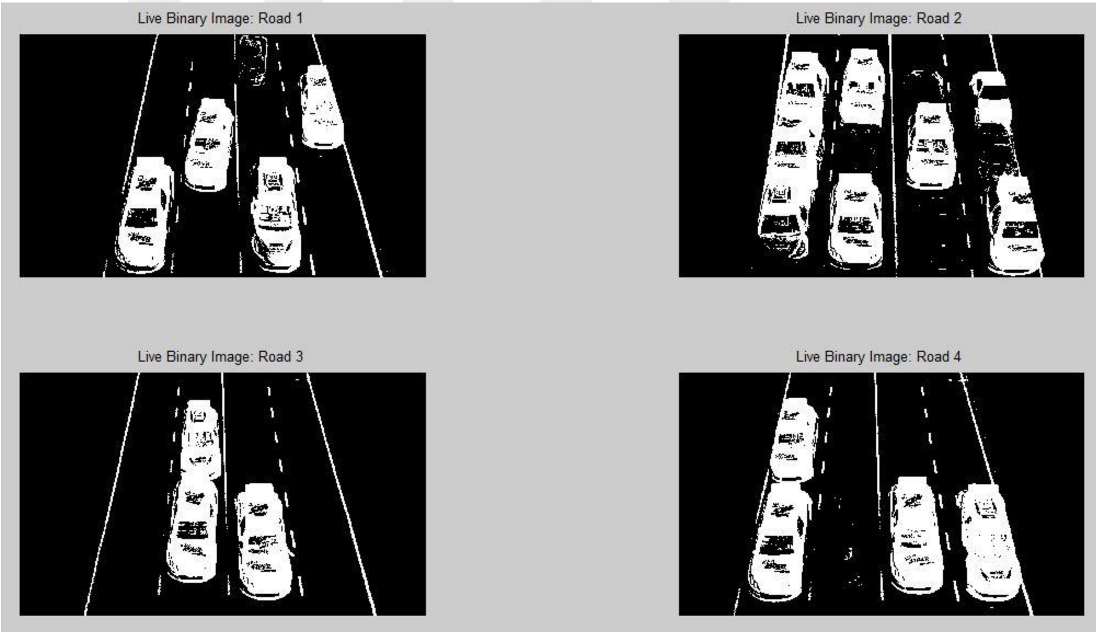


Figure 4.8 Converting live road images to binary image

4.5. Apply Morphological Operators

Different morphological operators described in subsections 4.5.1 to 4.5.3 are applied to the binary images obtained in Section 4.4 (after RGB to binary conversion operation) for making final decision. For this purpose morphological operators are implemented with different structural elements for both reference images and live road images. In all cases square structure element type (Chapter 2) is used (See Section 2.2.2.2 for this preference).

4.5.1. Image Dilation

This is the first operator performing dilation operation on Figure 4.7 and 4.8. Two different structural element sizes are selected for the same type of structure element: The structure element sizes are 4 and 9. The results of dilation operation of reference binary image are shown in Figure 4.9 for structure element size 4 and in Figure 4.10 for element size 9. For corresponding structure element sizes binary live images are shown in Figures 4.11-4.12 respectively.

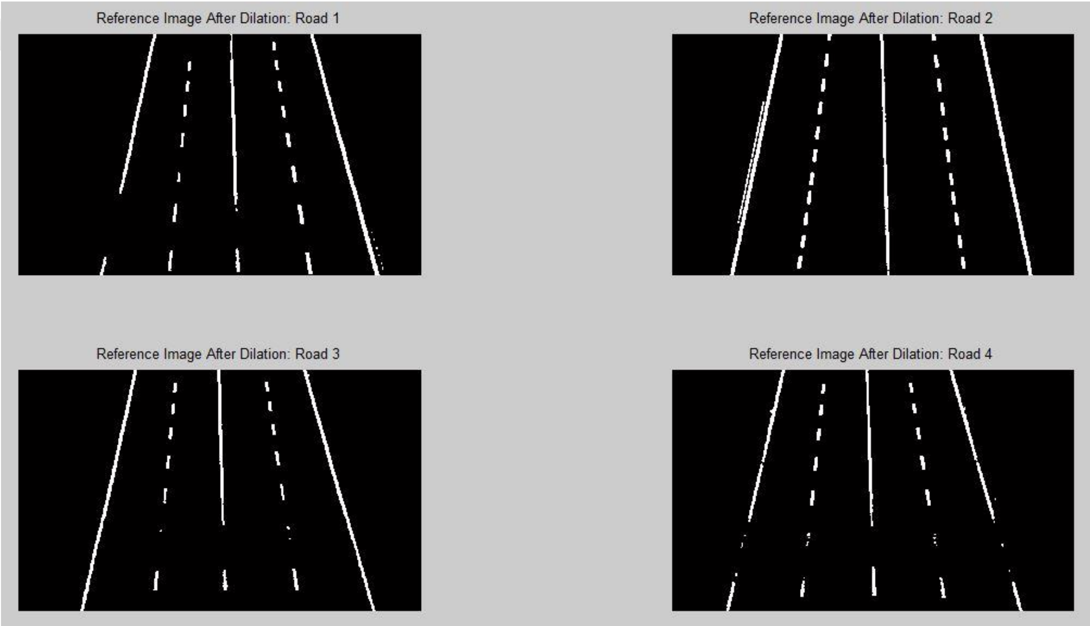


Figure 4.9 Reference image after dilation (Structure element: square, size: 4)

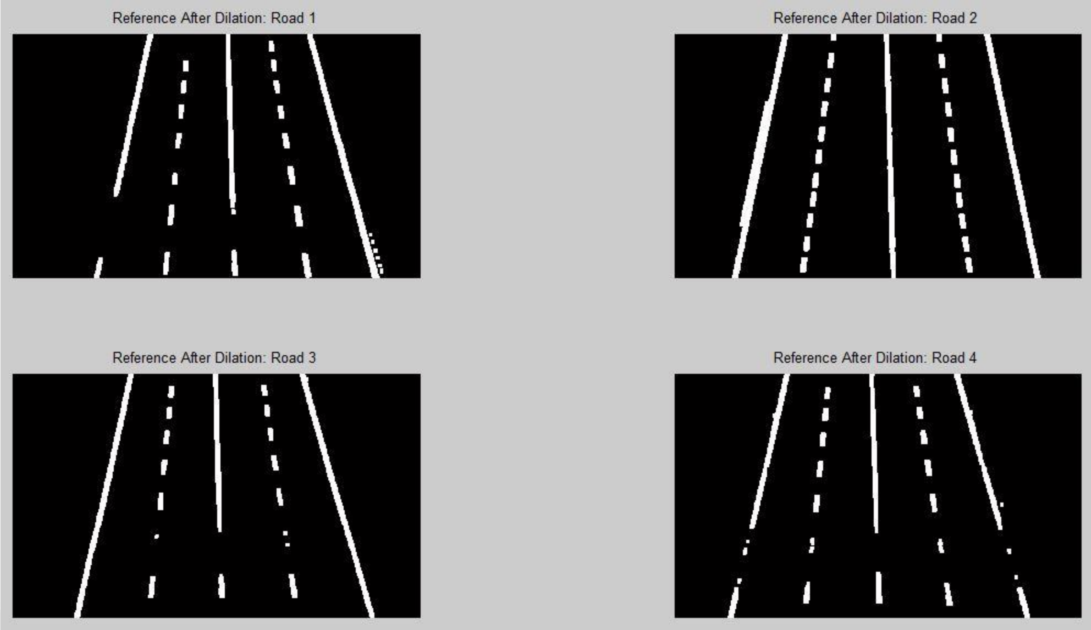


Figure 4.10 Reference image after dilation (Structure element: square, size: 9)

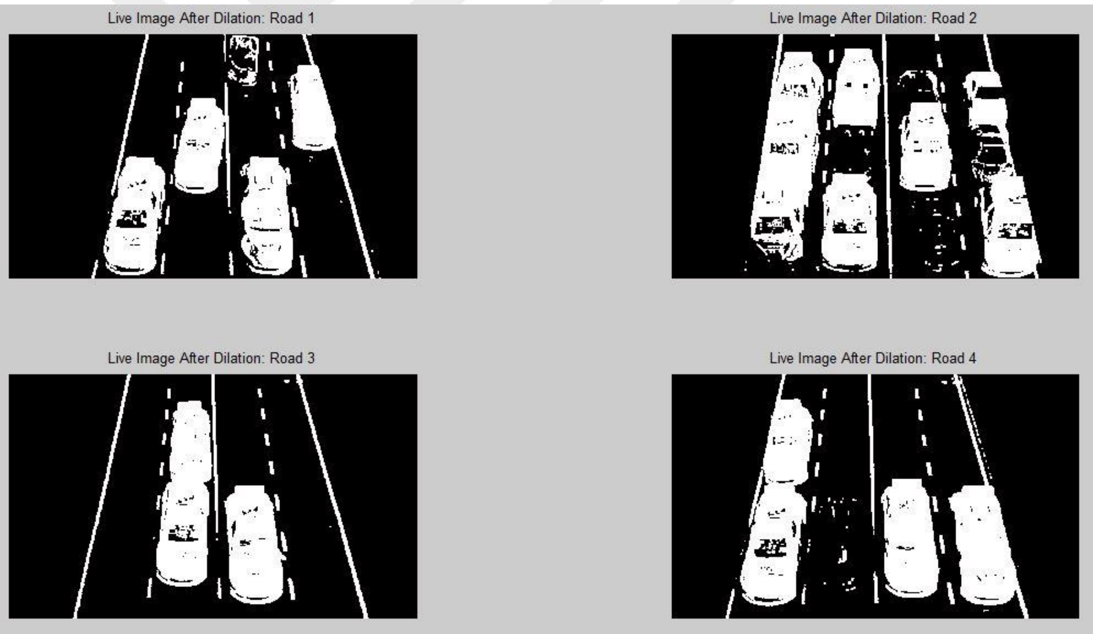


Figure 4.11 Live image after dilation (structure element: square, size: 4)

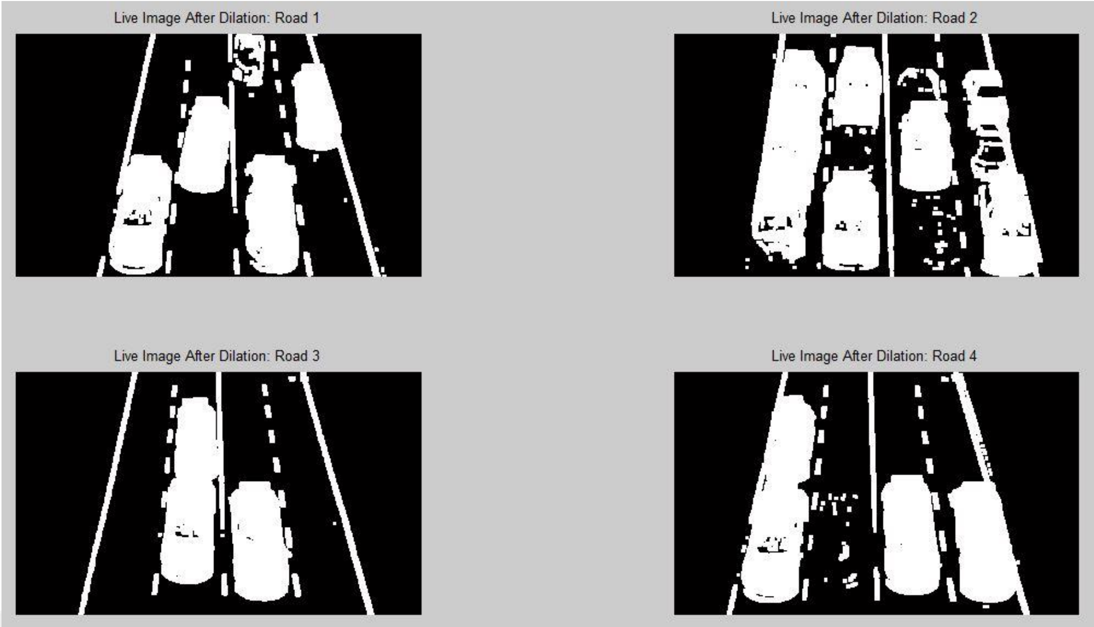


Figure 4.12 Live image after dilation (structure element: square, size: 9)

If we compare empty roads images shown in Figures 4.7 to dilated images shown in Figures 4.9 and 4.10, road side separation lines gets ticker for both structure element sizes 4 and 9. Also, comparing live road images shown in Figure 4.8 to dilated live road images shown in Figures 4.11 and 4.12, vehicle images notably are extended for both structure element sizes 4 and 9.

4.5.2. Image Erosion

Similar to the dilation operation, this operator is applied on both binary empty road reference images shown in Figure 4.7 and binary traffic live images shown in Figure 4.8. The results of erosion operations on the reference images of four empty roads are shown in Figure 4.13 and 4.14, and on the live traffic images are shown in Figure 4.15 and 4.16 for both structure element sizes 4 and 9, respectively.

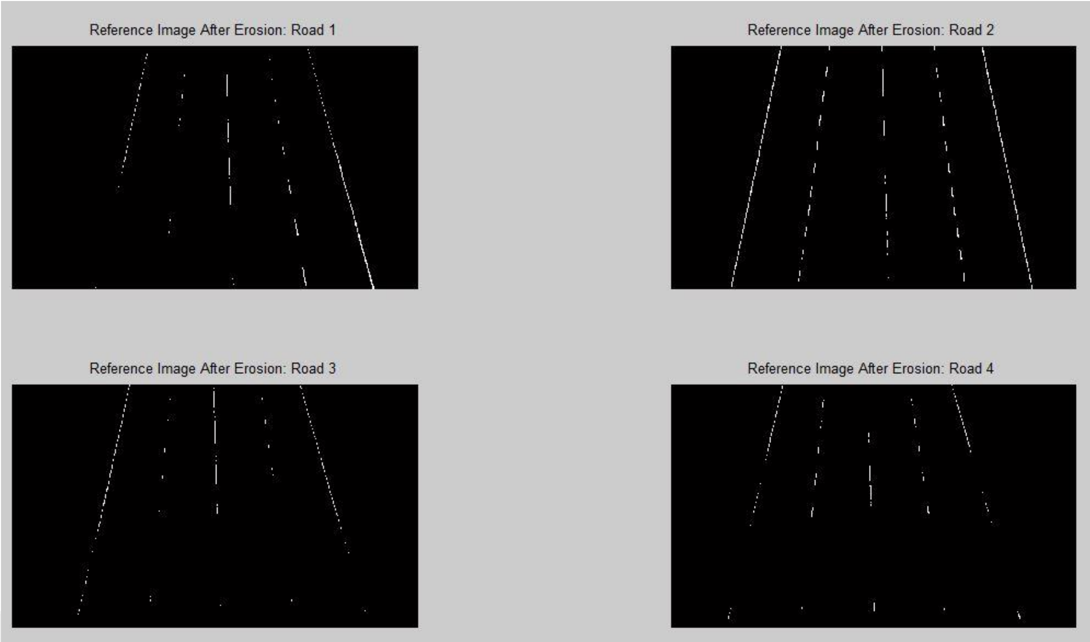


Figure 4.13 Reference image after erosion operation (structure element: square, size: 4)

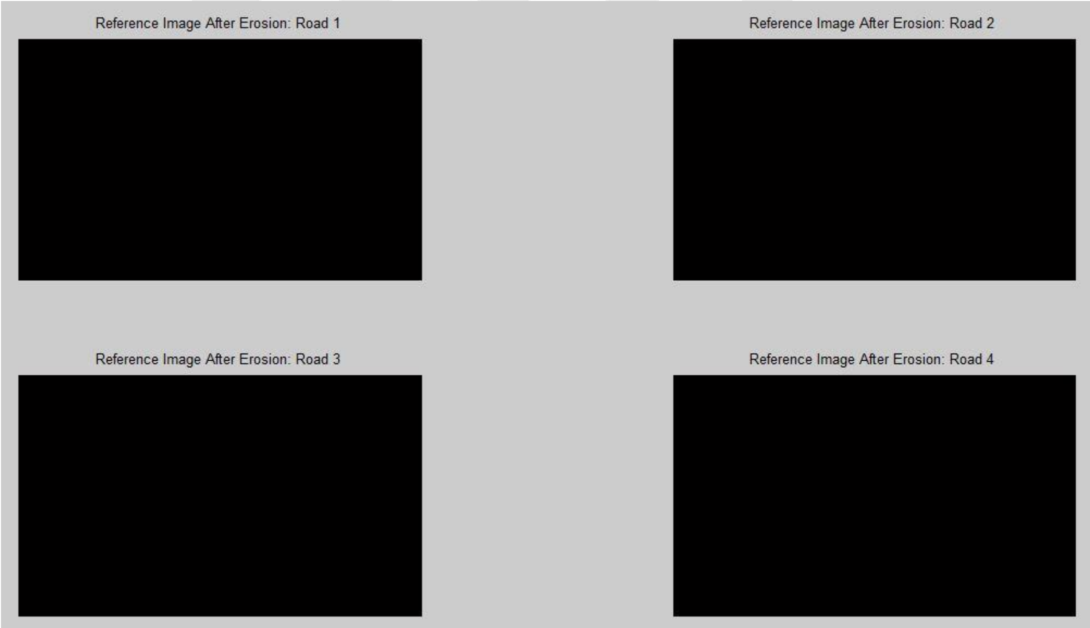


Figure 4.14 Reference image after erosion operation (structure element: square, size: 9)

Figure 4.15 Live image after erosion operation (structure element: square, size: 4)

Figure 4.16 Live image after erosion operation (structure element: square, size: 9)

If we compare empty roads images shown in Figures 4.7 to eroded image shown in Figures 4.13 and 4.14, road side separation lines gets thinner for both structure element sizes 4 and 9. Also, comparing live road images shown in Figure 4.8 to eroded live road images shown in Figures 4.15 and 4.16, vehicle images notably get shrinks for both structure element sizes 4 and 9. However this operator caused all roads side lines to become fainter for structure element size 4 or to disappear for structure element size 9.

4.5.3. Edge Detection

Some researchers [4, 9, 12] are used morphological image processing technique to detect edges. Edge detection based morphological image processing with structure element size 4 and 9 are shown in Figures 4.17 and 4.18 for empty road (reference) images and in Figure 4.19 and 4.20 for live traffic images. Simplest way to find edge detection in the morphological image processing technique [4, 24] which applies to images resulted from dilation and erosion operations follows the equation.

$$\text{Edge Detection} = \text{Image dilation} - \text{Image Erosion} \tag{4.2}$$

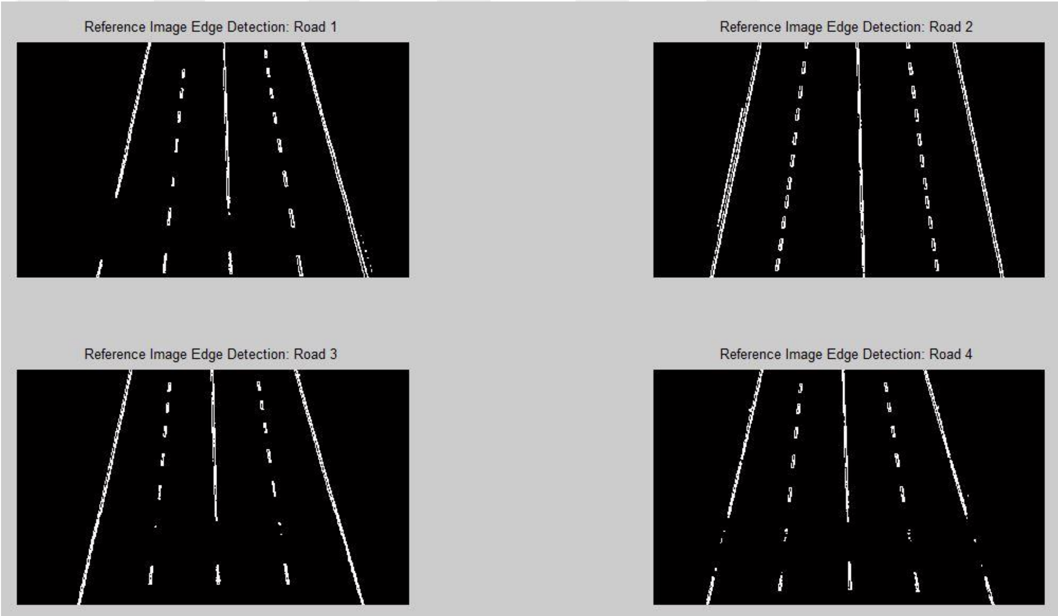


Figure 4.17 Reference image edge detection obtained after (Structure element: square, size: 4)

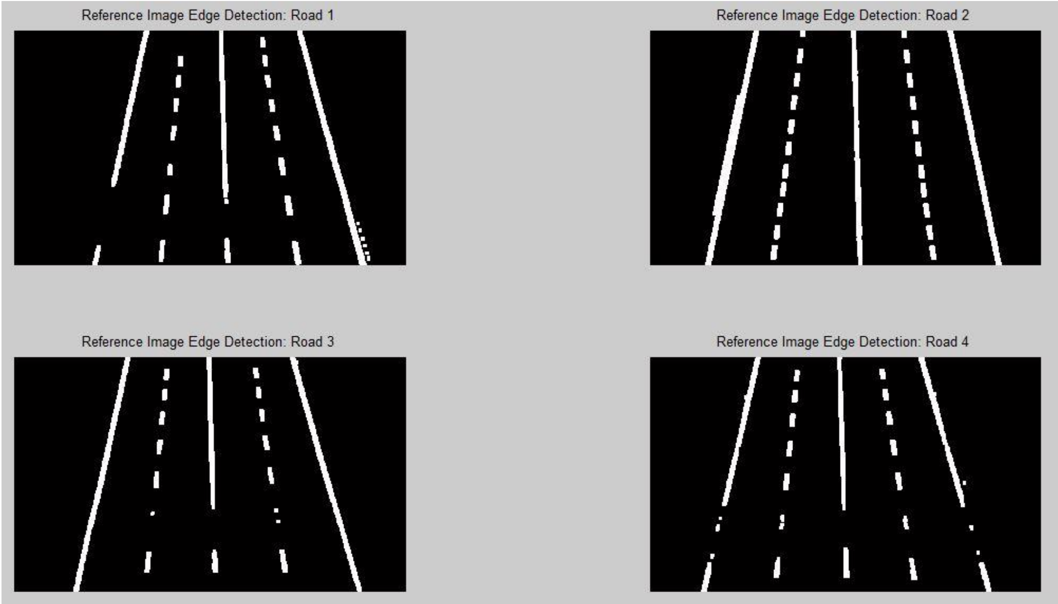


Figure 4.18 Reference image edge detection obtained after (Structure element: square, size: 9)

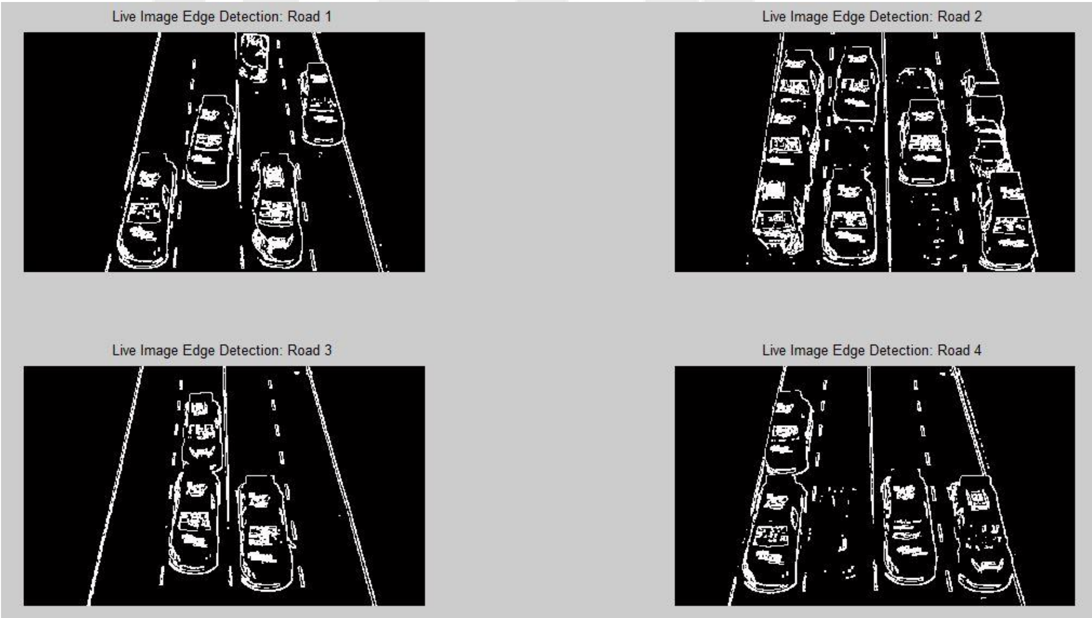


Figure 4.19 Live image edge detection obtained after (structure element: square, size: 4)

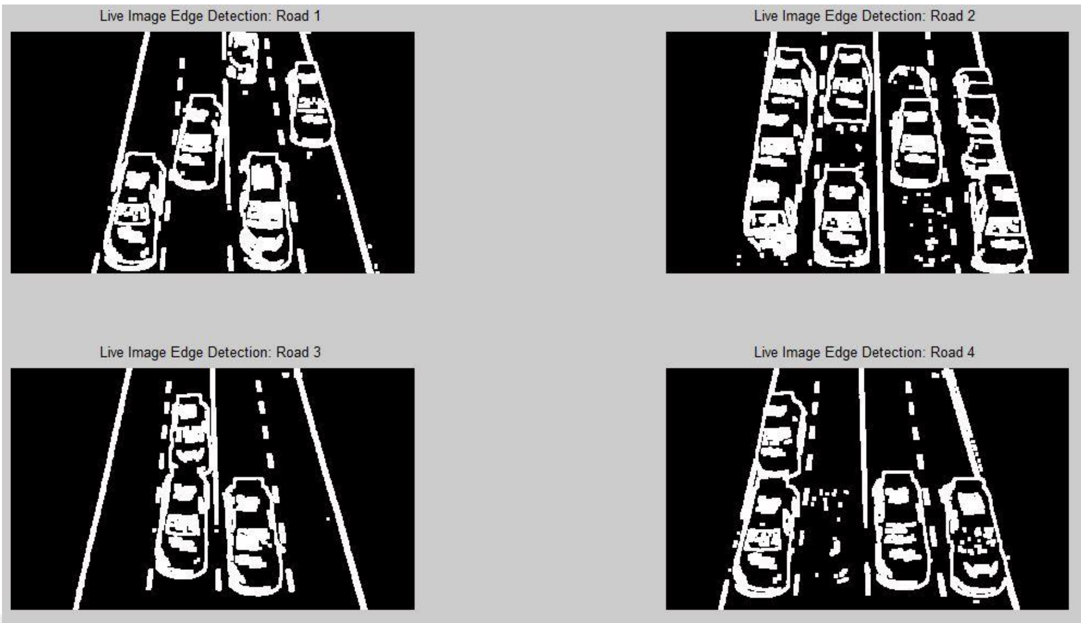


Figure 4.20 Live image edge detection obtained after (structure element: square, size: 9)

Comparing images in Figures 4.17 and 4.18 to the line images in empty roads became more distinct with structure element size 9 than element size 4. Further vehicle edge profiles become more divergent for both structure element size 4 and 9 but become more distinctive for structure element size 9. Hence, this operation provides more clear line images.

4.6. Comparison of Image Areas

The matching scores computed for the empty road (reference) images and for the vehicle area images are given in the inserts of Figure 4.21 to Figure 4.25. In Figure 4.21 images obtained without any morphological operations and in Figure 4.22 and 4.23 images obtained after dilation operation with structure element sizes 4 and 9 are shown respectively. In addition erosion matching scores with structure element size 4 and 9 after the erosion operation are given in Figure 4.24 and 4.25.

The matching scores of all images are listed in Table 4.1 and results are discussed in Section 4.7.

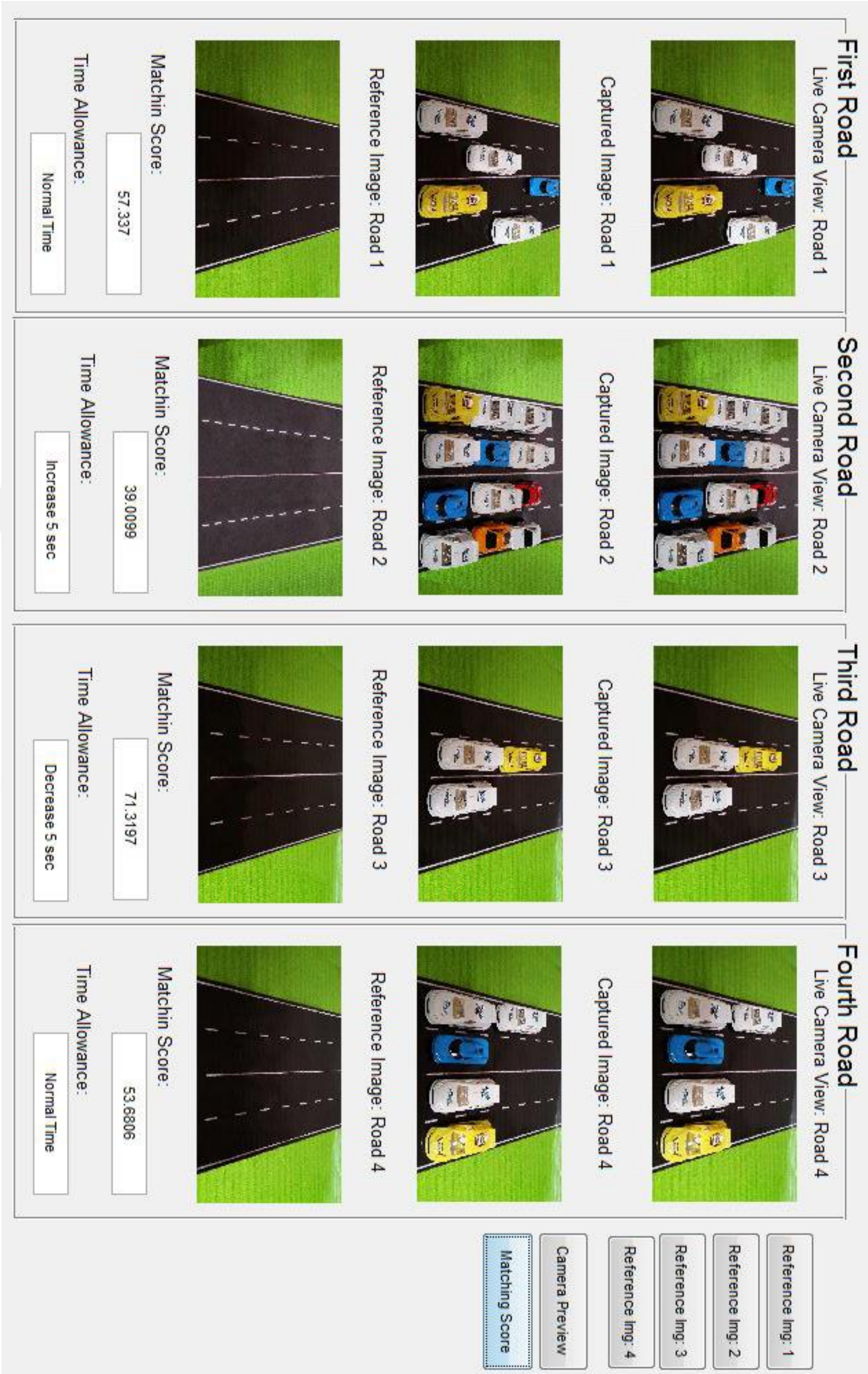


Figure 4.21 Binary images of four roads *not* subjected the morphological operations, and corresponding matching score

Figure 4.22 Binary images of four roads after morphological *dilation* operation and the corresponding matching scores where structure element: square, size: 4.

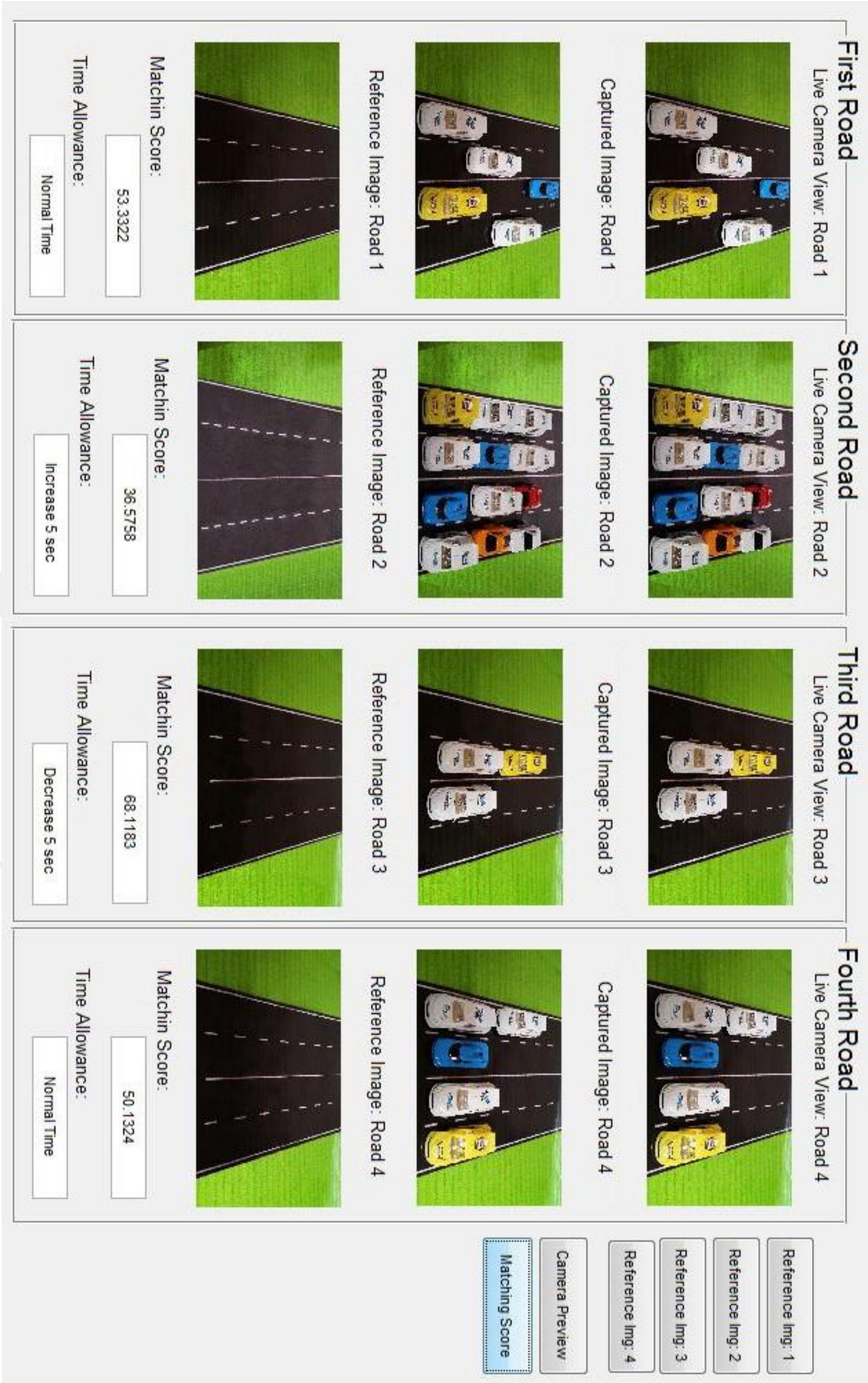


Figure 4.23 Binary images of four roads after morphological *dilation* operation and the corresponding matching scores where structure element: square, size: 9.

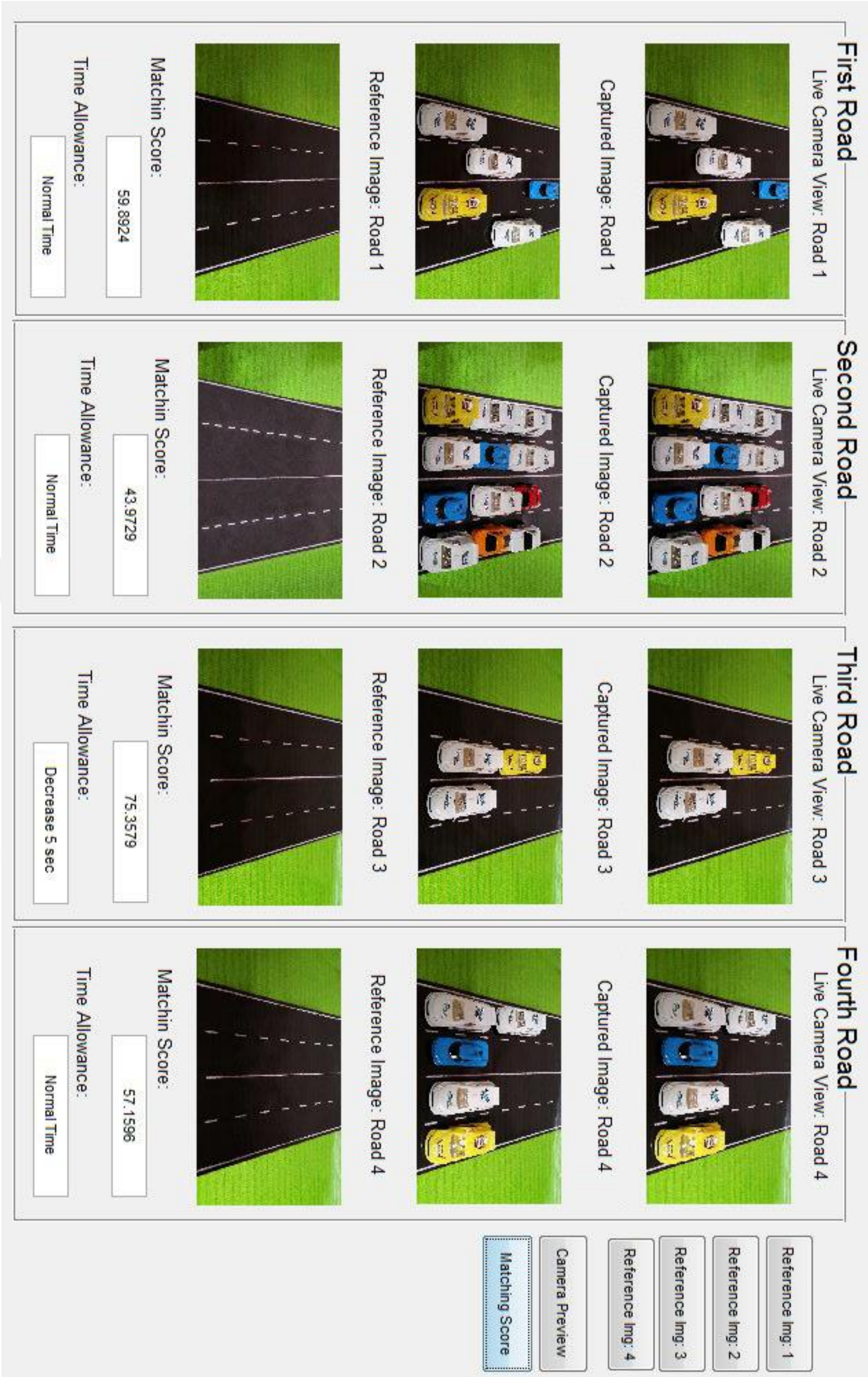


Figure 4.24 Binary images of four roads after morphological *erosion* operation and the corresponding matching scores where structure element: square, size: 4

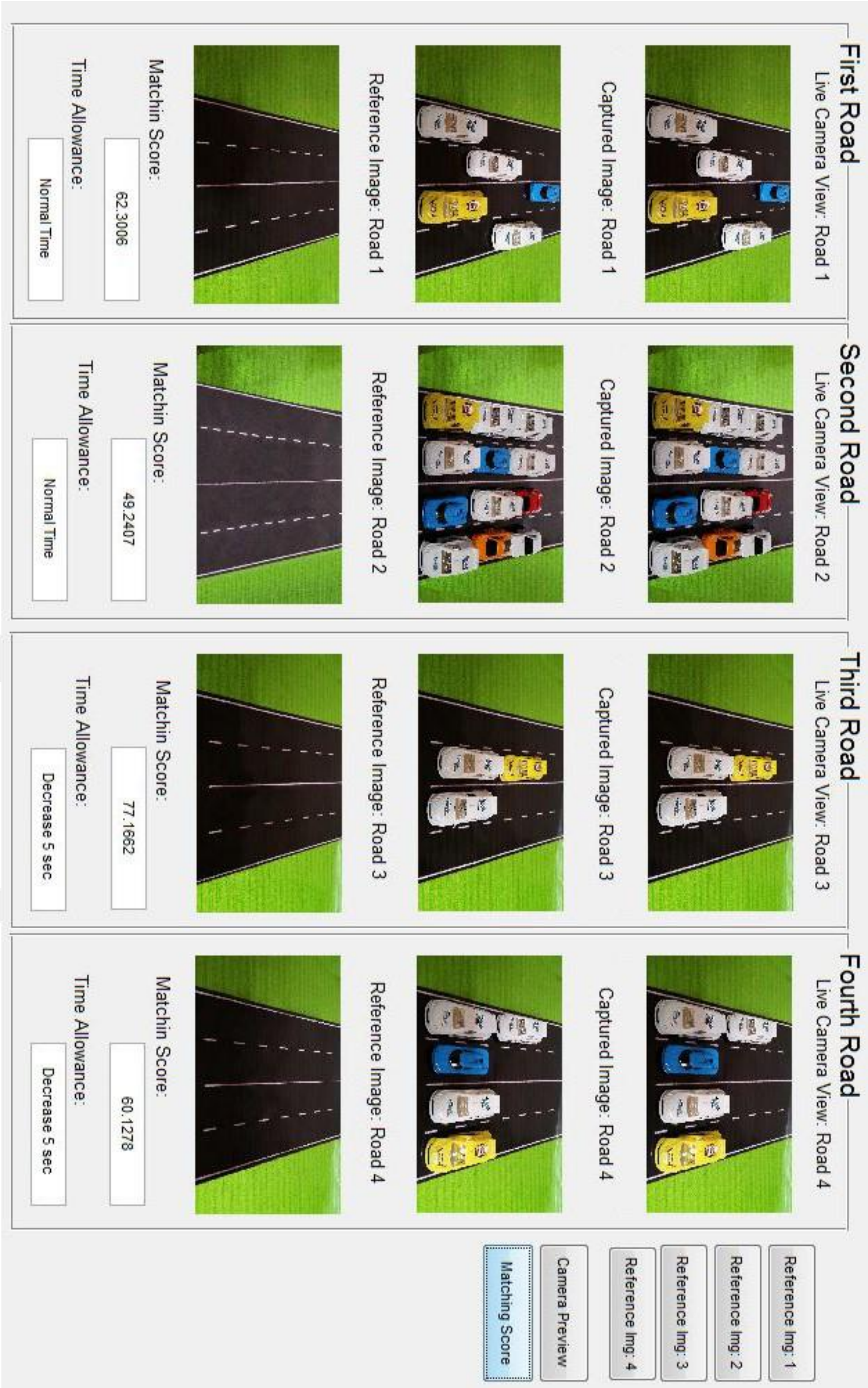


Figure 4.25 Binary images of four roads after morphological *erosion* operation and the corresponding matching scores where structure element: square, size: 9.

4.7. Discussion

To start up a sequence of traffic signaling and to decide green signaling duration for any of four roads, five tests are performed on the reference and the real traffic images for each road: First test is for binary comparison of the reference and the real traffic images, second and third tests are for morphological dilation (enlargement) operations with 4 and 9 structural element sizes of square structure element, and fourth and fifth tests are for morphological erosion (reduction) operations with the same size and square structure element. The matching scorers computed for each road are shown in Table 4.1 and the corresponding time durations for deciding green signaling are given in Table 4.2.

Table 4.1 Tests applied to detect matching scores before (3rd row) and after applying morphological operations

Tests	Operations	1st Road	2nd Road	3rd Road	4th Road
1	Binary image comparison(without morphological operations)	57.33	39.00	71.31	53.68
2	Dilation, size: 4	55.02	37.44	69.11	51.40
3	Dilation, size: 9	53.19	36.21	68.59	50.83
4	Erosion, size: 4	59.89	43.97	75.35	57.15
5	Erosion, size: 9	62.30	49.24	77.16	60.12

Table 4.2 Time allowance

Operations	1st Road	2nd Road	3rd Road	4th Road
Without Morphological Operations	Normal time	Increase 5 sec	Decrease 5 sec	Normal time
Dilation, size: 4	Normal time	Increase 5 sec	Decrease 5 sec	Normal time
Dilation, size: 9	Normal time	Increase 5 sec	Decrease 5 sec	Normal time
Erosion, size: 4	Normal time	Normal time	Decrease 5 sec	Normal time
Erosion, size: 9	Normal time	Normal time	Decrease 5 sec	Decrease 5 sec

Comparison of the reference and real traffic images obtained before and after the morphological operations is the basic tool to decide for green signaling duration. For example, in Table 4.1 although the image of the road 2 has the smallest matching score before applying morphological operations, but after performing the dilation operation on the same image with 4 and 9 structural element size, causes the matching scores to decrease by 4% and 7.1% respectively. However, the erosion operation on the images does not produce improvement on the matching scores, but rather increases them by 12.7% and 26.2%, respectively.

The decision for the green light duration for 2^{nd} road is given in the column 3 of Table 4.2, which corresponds to the case with lowest matching scores. This is the road to be depleted by allowing 5 sec more to the normal green signal duration initially set, totaling to 35 sec (30 sec allowance for green signaling shall be assumed to be normal active duration).

Since the matching score of 3^{rd} road is the highest, it is expected that the results indicate the normal signaling duration should be decreased by 5 sec, and for 1^{st} road having moderate matching score the normal signaling duration should be set.

For 4^{th} road the matching scores obtained after two dilation operations and one erosion operation with structure element size 4 indicate green signaling duration should be set to normal, but 5 sec decrease of normal duration is required with the erosion operation with structure element size 9 hence green signal duration should be set to 25 sec.

CHAPTER 5

DISCUSSION AND CONCLUSION

Implementation of the morphological image operators are discussed from the results obtained from the simulated crossroad model representing highway crossroad, and final discussions are made on the distinctive findings.

5.1. General Discussion

In the present work the test image data was obtained from a simulated crossroad model. The image data was captured and processed in binary form rather than gray or RGB images. This is because binary form of images is computationally more faster, and is found to be insensitive to environmental and weather conditions, and makes comparisons of matching score easy.

In order to have accurate image matching scores, there is a need to change structure elements sizes and types. In the present work, square structure element is selected because it is easy to implement in programming. Size 4 and size 9 are selected because it is found [20] that both sizes require less computational time with better accuracy in determining matching scores.

In the literature the morphological image processing is applied to detect edge distortion caused by vehicles and by undesired factors like damaged road or white marks on the road surfaces, shadows of trees and buildings [4, 9]. The same technique is also applied elsewhere for edge detection using Canny edge method by computing matching scores [12].

In this work, in order to achieve more effective traffic signaling control with higher accuracy, the morphological image processing is carried out without applying edge detection procedure to increase and to decrease image matching scores. Further usage of binary images for traffic signaling control is applied for the first time.

5.2. Conclusion

At highway crossroads traditional traffic signaling control systems use standard time durations. This type of time setting has the drawbacks as keeping time durations longer or shorter causing time and fuel wastage. Recently, application of the method of image processing to set green signaling durations and hence performing any type of discrete time adjustment has shown the advantage of efficient traffic flow control at any type of highway junctions under different road and whether conditions.

In the present work implementation the morphological image processing technique for adjustment of green signaling duration for any type vehicle density at a junction is illustrated. During implementation of the morphological image processing technique we focus on the individual effect of each operator to enhance image quality and hence to improve the accuracy of matching scores. In the application of this technique all the required operators are used except the edge detection operator. Since we are basically interested in the area occupied by the vehicles along the roads of a junction, it is observed that ignoring edge detection operator does not produce any loss in the image quality, but rather increases the accuracy of image matching score results for long vehicles. Further, dilation operations are observed to produce low matching scores while erosion operations result in high matching scores for the same square structure element with two different structure element sizes. Hence, generally the matching score results are found to produce more discrete signaling durations usable for applications. However, the usage of binary images is founded to bring about inconclusive matching scores for vehicles having darker colors.

In general usage of the morphological image processing technique for detection of vehicle densities using the binary image data obtained along roads of a simulated junction model would seem to yield applicable time green signaling duration adjustment.

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APPENDIX A

PROOF DUALITY PRINCIPLE

To prove the validity of duality principle, we start with the erosion definition:

$$(A \ominus B)^c = \{z | (B)_z \subseteq A\}^c$$

If set $(B)_z$ is contained in A, then $(B)_z \cap A^c = \emptyset$ and

$$(A \ominus B)^c = \{z | (B)_z \cap A^c = \emptyset\}^c$$

But the complement of the set of z's satisfying the previous equation is such that

$$(A \ominus B)^c = \{z | (B)_z \cap A^c \neq \emptyset\} = A^c \oplus \hat{B}$$

APPENDIX B

PROPERTIES OF CAMERAS AND PCI INTERFACE UNITS

1. *The Cameras*: USB HD Video webcam camera for PC

Features:

No Drivers, just plug and play.

Funky and sleek design

Offers crisp and clear images

Excellent performance in both still and moving images

Easy operation: plug and play

Plus, view accurate, true-to-life color

High-speed USB 2.0 interface

With this widescreen webcam, you can also fit multiple people in your picture or video at the same time.

Specifications:

Capture format: General 160x120, 176x144, 320x240, 352x288, 640x480, and 800x600.

Output format: RGB24

Mini sensitivity: 2.0V/Lux. Sec

Focus range: 20mm ~ Extremely

View: 50m~ infinity

Flash control: 50Hz or 60Hz

Max Dynamic Resolution: 1280x960 pixels

Supported Operating System: Windows 2000/XP/Vista/Win 7/8,Linux, Mac OS 10.4.6 or higher

Unit fps format: BMP / JPG

Dynamic format: AVI

Operating temperature: 0-40^{o} C

Dimensions: 6.2 x 5.1 x 6.7cm

2. *PCI interface unit*: S-Link type (4 Port USB3.0 Pci Express card: SL-3EX6)
Features:

Compliant with USB3.0 specification revision 1.0
Supports low-speed (1.5mbs)/full speed (12mbps)/high-speed (480mbps)/super-speed (5gbps)
Support 4 downstream ports for all speeds
Support all compliant USB compliant data transfer type as

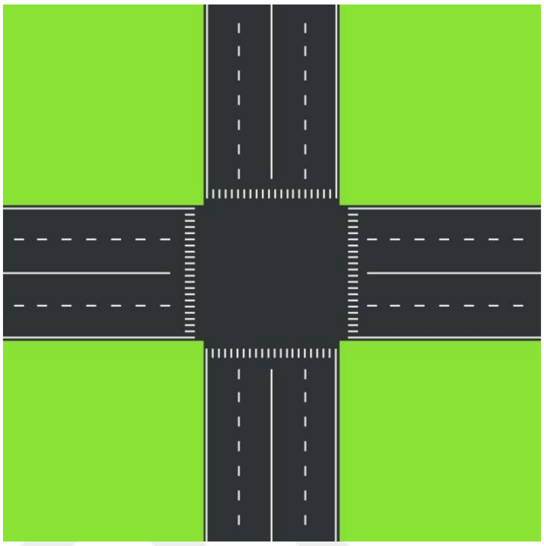
Follows:
Control/bulk/interrupt/isochronous transfer
Compliant with intel's extensible host controller Interface (xhcl) specification version

Software support:
Windows 95, 98, 98, ME, 2000, NT 4.0, XP, Vista, win7, win8, Linux, and DOS operating system.

APPENDIX C

IMAGES OF CAMERAS AND SIMULATED MODEL OF TRAFFIC

Cameras



Roads

Simulated model of traffic