UNIVERSITI PUTRA MALAYSIA

COLOR IMAGE SEGMENTATION BASED ON BAYESIAN THEOREM FOR MOBILE ROBOT NAVIGATION

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BY

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Image segmentation is a fundamental process in many image, video, and computer vision applications. Object extraction and object recognition are typical applications that use segmentation as a low level image processing. Most of the existing color image segmentation approaches, define a region based on color similarity. This assumption often makes it difficult for many algorithms to separate the objects of interest which consist of highlights, shadows and shading which causes inhomogeneous colors of the objects' surface.

Bayesian classification and decision making are based on probability theory and choosing the most probable or the lowest risk. A useful property of the statistical classifier like Bayesian is that, it is optimal in the sense that it minimizes the expected misclassification rate. However when the number of features increased, Bayesian classifier is quite expensive both in terms of computational time and memory. This thesis proposes a Bayesian color segmentation method which is robust and simple for real time color segmentation even in presence of environmental light effect. In this study a decision boundary equation, which is acquired from class conditional

probability density function (PDF) of colors, based on Bayes decision theory has been used for desired color segmentation. The estimation of unknown PDF is a common problem and in this study Gaussian kernel function which is most widely used nonparametric density estimation method has been used for PDF calculation.

Comparisons were made between the proposed method to the k-nearest neighbor (KNN) and support vector machine (SVM), methods for image segmentation. Experimental results show that the proposed algorithm works better than other two methods in terms of classifier accuracy with result of more than 99 percent successful segmentation of desired color in varying illumination. In order to show the real time ability and robustness of proposed method for color segmentation, experimental results conducted on vision based mobile robot for navigation. First the robot was trained by some training sample of desired target color in environment. The decision boundary which acquired in the teaching phase has been used for real time color segmentation as the robot move in the environment. Spatial information of desired color in segmented image has been used for calculating the robot heading angle which is used by mobile robot controller for navigation.

However, all of the existing color image segmentation approaches are strongly application dependent. This study shows that proposed algorithm successfully cope with the varying illumination which causes uneven colors of the objects' surface. The experimental results show the proposed algorithm is simple and robust, for real time application on vision based mobile robot for navigation, in spite of presence of other shapes and colors in the environment.

Abstrak tesis yang dipersembahkan kepada Senat Universiti Putra Malaysia

bagi memenuhi syarat untuk kelayakan menerima Sarjana Sains

SEGMENTASI IMEJ BERWARNA BERDASARKAN TEOREM BAYES

DAN JANGKAAN KETUMPATAN KERNEL UNTUK APLIKASI NAVIGASI ROBOT

Oleh

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Segmentasi imej merupakan suatu proses asas dalam pelbagai aplikasi imej, video dan penglihatan komputer. Pengekstrakan dan pengecaman objek adalah contoh aplikasi yang lazimnya menggunakan segmentasi sebagai langkah pemprosesan tahap rendah. Kebanyakan sistem segmentasi imej yang sedia ada mendefinisikan suatu kawasan itu berdasarkan kepada keserupaan warnanya. Ini menimbulkan kesukaran bagi kebanyakan algoritma untuk membezakan objek yang dicari yang biasanya terdedah kepada keterangan, bayangan dan penggelapan yang boleh menyebabkan ketidaksamaan warna kelihatan pada permukaan objek tersebut.

Pengelasan dan pembuat keputusan Bayesian adalah berdasarkan kepada teori kebarangkalian dan keputusan yang diambil adalah yang paling tinggi kebarangkaliannya atau yang paling kecil risikonya. Satu ciri penting pengelas statistik seperti Bayes ialah sifat optimalnya dalam cara ia meminimakan kadar jangkaan pengelasan yang salah. Namun demikian, apabila bilangan ciri ditambah, pengelas Bayes menjadi agak berat dari segi keperluan pengkomputeran masa dan memori. Tesis

ini mencadangkan suatu cara segmentasi warna yang kental tapi mudah untuk aplikasi segmentasi masa sebenar walaupun dalam kehadiran kesan pencahayaan sekitar.

Dalam kajian ini, suatu persamaan keputusan sempadan yang diperoleh dari fungsi ketumpatan kebarangkalian (PDF) warna kelas bersyarat, yang berdasarkan kepada teori keputusan Bayes, telah digunakan untuk segmentasi warna yang dikehendaki. Jangkaan bagi PDF yang tidak diketahui merupakan suatu masalah yang biasa dan dalam kajian ini, jangkaan ketumpatan tidak parametrik telah digunakan untuk menjangka PDF.

Perbandingan telah dibuat antara teknik yang dicadangkan dengan teknik-teknik k-jirun terhumpir KNN dan hantun vektor mesin SVM dalam tujuan segmentasi imej. Keputusan eksperimen menunjukkan bahawa teknik yang dicadangkan berfungsi lebih baik daripada dua kaeduh di atas dari segi ketepatan pengelasun dengan memperoleh keputusan sebunyak 99 peratus kejayaan dalam mengsegmentasikan cahaya dikenenduki dulum ketiduksamaan pencahayaan. Bagi mempamerkan kebolehan masa sebenar dan kekentalan teknik ini bagi segmentasi imej, eksperimen dilakukan bagi tujuan navigasi robot berdasarkan penglihatan mesin. Mulanya, robot itu dilatih menggunakan sampel latihan yang terdiri daripada warna yang hendak disegmentasi dalam persekitarannya. Sempadan keputusan yang dibentuk daripada fasa pengajaran telah digunakan untuk segmentasi warna masa sebenar semasa robot bergerak dalam persekitarannya. Maklumat ruang warna yang dikehendaki telah digunakan untuk mengira sudut tuju robot yang digunakan oleh pengawal robot untuk navigasi.

Bagaimanapun, semua kaedah segmentasi imej yang sedia ada sangat bergantung kepada aplikasi di mana ia digunakan. Kajian ini menunjukkan bahawa teknik yang

dicadangkan berjaya menghasilkan keputusan yang baik walaupun dalam keadaan pencahayaan yang berubah lalu menyebabkan ketidaksamaan warna pada permukaan objek. Keputusan eksperimen membuktikan bahawa algorithma yang dicadangkan adalah mudah dan kental, sesuai untuk aplikasi masa sebenar navigasi robot, walaupun bentuk dan warna lain hadir dalam persekitaran.

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I certify that an Examination Committee has met on **Second of July 2009** to conduct the final examination of **Hamid Rahimizadeh** on his Master of Science thesis entitled "**Color Segmentation Based on Bayesian Theorem with Application to Mobile Robot Navigation**" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the relevant degree.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

HAMID RAHIMIZADEH

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LIST OF ABBREVIATIONS

PDF	PROBABILITY DENSITY FUNCTION
SVM	SUPPORT VECTOR MACHINES
LMA	LEVENBERG-MARQUART ALGORITHM
KNN	K NEAREST NEIGHBOR
ANN	ARTIFICIAL NEURAL NETWORK

CHAPTER 1

INTRODUCTION

1.1 Introduction

Image segmentation is the initial step in the most image analysis and pattern recognition application. Image segmentation partitions an image into non overlapping regions which ideally correspond to different real-world objects with respect to a chosen property. A region is defined as a homogeneous group of connected pixels. There are different ways to describe homogeneity of a region for example color, gray levels, motion and texture. However overlapping among regions are not permitted and each pixel belongs only to a single region.

Image segmentation is a fundamental process in many image, video, and computer vision applications. In mobile robot navigation or particle classification for example, segmentation is a critical step towards content analysis and image understanding. Object extraction, object recognition and object-based compression are typical application that uses segmentation as a low level image processing. Haralick et.al [5] proposed four criteria that describe good segmentation. First regions should be uniform and homogeneous with respect to some characteristic(s), secondly adjacent regions should have significant differences with respect to the characteristic on which they are uniform. Third region interiors should be simple and without holes, and finally boundaries should be simple, not ragged, and be spatially accurate.

Based on criteria mentioned above, it is possible to divide segmentation into two categories. The first two criteria examine characteristics of objects in the image, which

can be named as characteristic criteria. The last two criteria are based on how likely each region is regarded as a single object by people, which can be classified as semantic criteria.

Segmentation result from either characteristic criteria or semantic criteria can be done in different color space or with different methods. They are key base for many higher level image processing activities.

In general, image segmentation methods can be divided into three categories: pixel-based methods, region-based methods, and boundary-based methods. Pixel-based methods group the pixels with similar features, such as color or texture, without considering the spatial relationship among pixel groups, consequently regions formed with these segmentation methods can be non-contiguous. Our proposed Bayesian classification method can be categorized into pixel based methods. In region-based methods, objects are defined as regions of pixels which have homogeneous characteristics. Region based methods group the pixels according to their similarities and spatial connectedness.

The third category of segmentation methods, boundary based methods, are quite distinct from pixel and region based methods. In boundary-based methods, objects are defined as pixels surrounded by closed boundaries. In contrast with pixel-based and region-based methods, boundary- based segmentation methods offer the potential advantage that pixels within a closed boundary can have significant variations in their characteristics.

1.2 Problem Statement

Image segmentation problem is basically one of psychophysical perception, and therefore not susceptible to a purely analytical solution [2]. Segmentation may also be viewed as image classification problem based on color and spatial features [37]. Statistically based classification methods have been in existence for a long time. These are based on probabilities that a given set of measurements come from objects belonging to a certain class. A useful property of the statistical classifier like Bayes is, that it is optimal in the sense that it minimizes the expected misclassification rate [58], however when the number of features increased, that makes the Bayesian classifier is quite expensive both in computational time and memory [9].

Color can be useful feature in machine vision, for task like target color segmentation in an autonomous system. One of the main problems with target color segmentation is that, the color or specifically the apparent color of an object depends on illumination; the reflectance of the object, illumination geometry, viewing geometry and sensor parameters, all them make the color shift and has the influence on the result of target color segmentation algorithm [52]. Color segmentation methods proposed recently do address these issues, however with expense of computational complexity. Therefore finding the real time algorithm with low misclassification rate that addressed the above mentioned issue is desired.

1.3 Aim and Objectives

In this thesis the main aim is designing a real-time color segmentation method based on Bayesian theorem, the main goals are as follows

- To estimate the two dimensional probability density functions based on color feature vectors by non parametric method in feature space.
- To find the decision boundary for color segmentation by identifying the most probable area in two dimensional probability density function of feature vectors.
- To evaluate the result of the proposed Bayesian color segmentation in different illumination condition.
- To apply the proposed Bayesian color segmentation on vision based mobile robot for navigation.

The idea is by finding decision boundary of most probable area; desired color segmentation can be done by applying resulted equation on image. For probability density function estimation since there is no prior information for color features distribution, nonparametric density estimation method will be used. In order to evaluate the result of proposed method, comparison will be done between proposed method, SVM and KNN methods which both are supervised classification methods.

One of the main drawbacks with the statistical based and supervised image segmentation method is, these methods are computationally expensive. In order to examine the real time ability and robustness of the proposed method for the desire color segmentation, the proposed algorithm has been applied on vision based mobile robot for navigation.

1.4 The Scope of the Work

The proposed method is applicable for desire color segmentation in the image based on Bayesian theorem and nonparametric PDF estimation from training sample which acquired from the color feature vectors in HSL color space. This method is sample based classification so variation in the training sample may affect the result of segmentation. First the classifier should train with samples of each class. If the lighting condition changes dramatically after classifier training, the classifier needs to be retrained for new lighting conditions. This algorithm has been applied on vision based mobile robot for navigation. The LabView has been used as software platform and 6229 USB data acquisition has been used as hardware platform. The navigation environment could be indoor or outdoor. Because of presence of same color, like target color in the environment, sometimes other image processing function has been used for removing the noise

1.5 Outline of the Thesis and Contributions

This thesis is made up of five chapters. The first chapter is the introduction that includes background overview, problem statement, outline and scope of works. Chapter 2 starts with reviewing of the monochrome image segmentation, and color image segmentation methods. Advantages and disadvantages of region based approach discussed in this chapter. In addition, fuzzy based image segmentation approach and neural networks approach are reviewed and the advantages and drawbacks of these methods are discussed. Finally, the statistical based segmentation algorithm based on Bayesian

theory is discussed, the different approach for probability density function estimation described.

In chapter 3 the principle of Bayesian theory is introduced. The method for estimating the probability density function based on nonparametric method from color value feature vectors is presented. From the probability density function based on the Bayes decision theory, most probable area has been plotted on HSL color space and then mathematical equation of this area is used for the desire color segmentation. In chapter 4 experimental results of the proposed method on different color images in different lighting conditions are prescribed. In order to evaluate the result of the proposed method, comparison with the SVM and KNN classification methods in terms of classifier accuracy are carried out. In the last part of chapter 4 the proposed algorithm is applied onto vision based mobile robot for navigation. Finally the conclusion is given in chapter 5 and some perspectives for future work are suggested.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In computer vision, segmentation refers to the process of partitioning a digital image into multiple regions (sets of pixels). The goal of segmentation is to simplify and/or change the representation of an image into something that is more meaningful and easier to analyze [22]. Image segmentation is typically used to locate objects and boundaries (lines, curves, etc.) in images. The result of image segmentation is a set of regions that collectively cover the entire image, or a set of contours extracted from the image. Each pixel in a region is similar with respect to some characteristic or computed property, such as color, intensity, or texture. Adjacent regions are significantly different with respect to the same characteristic(s) [22].

A formal definition of image segmentation is as follows [1]: If we have a digital image, then segmentation is a partitioning the image into connected subsets or regions $(R_1, R_2, \dots, R_n)$ such that,

$$\bigcup_{i=1}^{n} R_i = F \text{ ,with } R_i \cap R_j = \emptyset \quad (i \neq j). \tag{2.1}$$

Image segmentation is the first step in image analysis and pattern recognition, it is a key basis of many higher level image processing activities. In this chapter the different approaches for image segmentation are reviewed and advantages and the disadvantages of each image segmentation technique are discussed.