Image Thresholding Technique

Based On

Fuzzy Partition And Entropy Maximization

Mansuo Zhao

A thesis submitted in fulfillment of the requirements for the degree of

Doctor of Philosophy

School of Electrical And Information Engineering

University of Sydney

December, 2004
Abstract

Thresholding is a commonly used technique in image segmentation because of its fast and easy application. For this reason threshold selection is an important issue. There are two general approaches to threshold selection. One approach is based on the histogram of the image while the other is based on the gray scale information located in the local small areas. The histogram of an image contains some statistical data of the grayscale or color ingredients. In this thesis, an adaptive logical thresholding method is proposed for the binarization of blueprint images first. The new method exploits the geometric features of blueprint images. This is implemented by utilizing a robust windows operation, which is based on the assumption that the objects have “C” shape in a small area. We make use of multiple window sizes in the windows operation. This not only reduces computation time but also separates effectively thin lines from wide lines. Our method can automatically determine the threshold of images. Experiments show that our method is effective for blueprint images and achieves good results over a wide range of images.

Second, the fuzzy set theory, along with probability partition and maximum entropy theory, is explored to compute the threshold based on the histogram of the image. Fuzzy set theory has been widely used in many fields where the ambiguous phenomena exist since it was proposed by Zadeh in 1965. And many thresholding methods
have also been developed by using this theory. The concept we are using here is called fuzzy partition. Fuzzy partition means that a histogram is parted into several groups by some fuzzy sets which represent the fuzzy membership of each group because our method is based on histogram of the image. Probability partition is associated with fuzzy partition. The probability distribution of each group is derived from the fuzzy partition. Entropy which originates from thermodynamic theory is introduced into communications theory as a commonly used criteria to measure the information transmitted through a channel. It is adopted by image processing as a measurement of the information contained in the processed images. Thus it is applied in our method as a criterion for selecting the optimal fuzzy sets which partition the histogram.

To find the threshold, the histogram of the image is partitioned by fuzzy sets which satisfy a certain entropy restriction. The search for the best possible fuzzy sets becomes an important issue. There is no efficient method for the searching procedure. Therefore, expansion to multiple level thresholding with fuzzy partition becomes extremely time consuming or even impossible.

In this thesis, the relationship between a probability partition (PP) and a fuzzy C-partition (FP) is studied. This relationship and the entropy approach are used to derive a thresholding technique to select the optimal fuzzy C-partition. The measure of the selection quality is the entropy function defined by the PP and FP. A necessary condition of the entropy function arriving at a maximum is derived. Based on this condition, an efficient search procedure for two-level thresholding is derived, which
makes the search so efficient that extension to multilevel thresholding becomes possible. A novel fuzzy membership function is proposed in three-level thresholding which produces a better result because a new relationship among the fuzzy membership functions is presented. This new relationship gives more flexibility in the search for the optimal fuzzy sets, although it also increases the complication in the search for the fuzzy sets in multi-level thresholding. This complication is solved by a new method called the "Onion-Peeling" method. Because the relationship between the fuzzy membership functions is so complicated it is impossible to obtain the membership functions all at once. The search procedure is decomposed into several layers of three-level partitions except for the last layer which may be a two-level one. So the big problem is simplified to three-level partitions such that we can obtain the two outmost membership functions without worrying too much about the complicated intersections among the membership functions.

The method is further revised for images with a dominant area of background or an object which affects the appearance of the histogram of the image. The histogram is the basis of our method as well as of many other methods. A "bad" shape of the histogram will result in a bad thresholded image. A quadtree scheme is adopted to decompose the image into homogeneous areas and heterogeneous areas. And a multi-resolution thresholding method based on quadtree and fuzzy partition is then devised to deal with these images.
Extension of fuzzy partition methods to color images is also examined. An adaptive thresholding method for color images based on fuzzy partition is proposed which can determine the number of thresholding levels automatically.

This thesis concludes that the "C" shape assumption and varying sizes of windows for windows operation contribute to a better segmentation of the blueprint images. The efficient search procedure for the optimal fuzzy sets in the fuzzy-2 partition of the histogram of the image accelerates the process so much that it enables the extension of it to multilevel thresholding. In three-level fuzzy partition the new relationship presentation among the three fuzzy membership functions makes more sense than the conventional assumption and, as a result, performs better. A novel method, the "Onion-Peeling method", is devised for dealing with the complexity at the intersection among the multiple membership functions in the multilevel fuzzy partition. It decomposes the multilevel partition into the fuzzy-3 partitions and the fuzzy-2 partitions by transposing the partition space in the histogram. Thus it is efficient in multilevel thresholding. A multi-resolution method which applies the quadtree scheme to distinguish the heterogeneous areas from the homogeneous areas is designed for the images with large homogeneous areas which usually distorts the histogram of the image. The new histogram based on only the heterogeneous area is adopted for partition and outperforms the old one. While validity checks filter out the fragmented points which are only a small portion of the whole image. Thus it gives good thresholded images for human face images.
Acknowledgments

This thesis is dedicated to my parents.

It has taken me three years to finish this thesis and during this time I became paralyzed after an accident. Running a program on my computer is not a major problem but typing up the results of my research with a stick attached to one hand became a big burden because I lost the good use of my hand. Also, the numerous health problems associated with the paralysis have always been in the way. This thesis could not have been completed without all the help and support I received from my supervisor Professor Hong Yan, my colleagues at the Image Processing Laboratory, and some of the staff at the School of Electrical and Information Engineering, the Engineering Faculty and the libraries at the University of Sydney.

I would like to take this opportunity to express my thanks to Professor Hong Yan for introducing me to the image processing area and his constant and inspiring supervision during the years. His patience and encouragement have been my strength to complete the study.

I am also very grateful for the assistance given to me by my colleagues at the Image Processing Laboratory. Of them all I would like to give my special thanks to Mrs. Yi Xiao who has provided lots of assistance to me. Many thanks also to Mrs. Yan Chang for her help with the revision of some of my papers and useful discussion on the topic. And thanks also go to Mrs. Qin Zhi Zhang for her assistance with my enrolment. I must also thank Mrs. Inge Rogers for proof reading this thesis and
correcting my English. I would like to express my gratitude to Miss Colleen Moore for her constant encouragement and help to get me necessary support from all kinds of resources.

I also want to thank my family for their love and support of me.
## Contents

1 Introduction ............................................................................................................. 1  
  1.1 Overview ............................................................................................................. 1  
  1.2 Adaptive Logical Method for Blueprint Images .............................................. 4  
  1.3 Entropy and Fuzzy Thresholding ................................................................. 6  
  1.4 Contributions of the Thesis .......................................................................... 11  
  1.5 Structure of the Thesis ................................................................................. 13  

2 An Adaptive Logical Thresholding Method for Binarization of Blueprint Images ................................................................................................................. 15  
  2.1 Review of Existing Thresholding Methods ................................................. 15  
      2.1.1 Global Thresholding Methods .............................................................. 15  
      2.1.2 Local Thresholding Methods .............................................................. 16  
  2.2 “C” Shape Method ......................................................................................... 23  
      2.2.1 Histogram Analysis of Blueprint Images ............................................ 24  
      2.2.2 “C” Shape Method .............................................................................. 24  
  2.3 Experiment Results and Evaluations ............................................................ 33  
  2.4 Summary ........................................................................................................ 40
4.5.1 Fuzzy Searching VS. Exhaust Searching ......................... 73
4.5.2 Fuzzy Entropy VS. Entropy ..................................... 76
4.5.3 Fuzzy Entropy VS. Other Entropy Methods ...................... 76
4.5.4 S Function VS. Linear Function ................................. 86
4.6 Summary ....................................................................... 87

5 Extension of Fuzzy Partition Technique in Three-Level Thresholding......................................................................... 88
  5.1 Probability Partition and Fuzzy Partition in Three Level Thresholding . . . . . 88
    5.1.1 Probability Partition ............................................ 88
    5.1.2 Fuzzy C-Partition ............................................... 89
  5.2 Membership Functions in Three Level Fuzzy Partition ....................... 92
  5.3 Searching Algorithms .................................................. 95
    5.3.1 Simulated Annealing Algorithm ................................. 95
    5.3.2 Genetic Algorithm .............................................. 99
    5.3.3 Fast Search Procedure ......................................... 101
  5.4 Results and Discussion .................................................. 106
  5.5 Summary ....................................................................... 110

6 Multilevel Thresholding .................................................. 116
  6.1 Membership Functions in Multilevel Thresholding ....................... 116
  6.2 Onion Peeling Method .................................................. 117
    6.2.1 First Layer Segmentation ...................................... 118
    6.2.2 Second Layer Segmentation .................................. 120
    6.2.3 Further Layer Segmentation ................................. 124
6.3 Examples ............................................................ 127
6.4 Searching Procedure ............................................. 131
6.5 Experiment Results ............................................... 134
6.6 Summary ............................................................ 151

7 Adaptive Multi-resolution Thresholding with Fuzzy Partition .. 153
   7.1 Quadtree Scheme ............................................... 153
   7.2 New Histogram of the Quadtree Image ....................... 157
   7.3 Local Fuzzy Partition ......................................... 160
      7.3.1 Local Histogram .......................................... 160
      7.3.2 Local Fuzzy Partition .................................... 161
   7.4 The Adaptive Segmentation Method ............................ 162
   7.5 Experiment Results and Discussion ........................... 164
   7.6 Summary ............................................................ 171

8 Adaptive Fuzzy Thresholding for Color Images .................. 173
   8.1 Simple Extension of Fuzzy Partition ........................ 175
      8.1.1 Two($2^3$)-Level Thresholding ........................ 175
      8.1.2 Three($3^3$)-Level Thresholding ........................ 178
   8.2 Adaptive Color Image Thresholding with the Quadtree Scheme 179
      8.2.1 The Algorithm of Adaptive Thresholding ............ 179
      8.2.2 Experiment Results ...................................... 180
   8.3 Summary ............................................................ 181
9 Conclusion ................................................................. 183
  9.1 Summary of Achievement ........................................... 184
  9.2 Discussion ............................................................. 187
  9.3 Suggestion for Further Research ................................. 189

Bibliography ......................................................................... 190

A Publications ......................................................................... 201
List of Figures

Figure 1.1 Blueprint images .................................................. 5

Figure 2.1 Windows used in the logical level technique ............... 21

Figure 2.2 Histograms of the blueprint images shown in Figure 1.1. .... 25

Figure 2.3 “C” shape masks ................................................ 26

Figure 2.4 Object has a “C” shape in a small area ....................... 27

Figure 2.5 Comparison between “C” windows operation and Yang and Yan’s method for large characters ........................................ 28

Figure 2.6 Comparison between “C” windows operation and Yang and Yan’s method for lines with different width ................................................................. 29

Figure 2.7 Binarized images with different window size ............... 30

Figure 2.8 Binarized images of Figure 1.1 (a) with different methods ... 36

Figure 2.9 Binarized images of Figure 1.1 (b) with different methods ... 37

Figure 2.10 Binarized images of Figure 1.1 (c) with different methods ... 38

Figure 2.11 Binarized images of Figure 1.1 (d) with different methods ... 39

Figure 2.12 Experiment result with multiple window operation .......... 41

Figure 2.13 Binarized images of Figure 2.12 (a) with some other methods .... 42

Figure 3.1 Entropy function vs probability ............................................ 47

Figure 3.2 Gray scale image of Lena ................................................ 52

Figure 3.3 Experiment results on the gray scale image of Lena with both Pun’s algorithms ............................................................................................................................. 54

Figure 3.4 Experiment result with Kapur’s method ....................... 56
Figure 5.4 Three-level thresholded kiosk image with the proposed method and the simulated annealing algorithm ................................................ 112

Figure 5.5 Three-level thresholded father-and-son image with the proposed method and the simulated annealing algorithm ................................................. 113

Figure 6.1 Fuzzy c-partition of n-level thresholding. ........................................ 117

Figure 6.2 Onion-peeling: first layer peeling ................................................. 120

Figure 6.3 Onion-peeling: second layer peeling. ............................................ 124

Figure 6.4 Gray scale face image....................................................... 128

Figure 6.5 Fuzzy partition in 5-level thresholding for the face image .......... 129

Figure 6.6 5-level thresholded image of the gray scale face image............ 130

Figure 6.7 Gray scale Lena image ......................................................... 131

Figure 6.8 Fuzzy partition in 5-level thresholding for the Lena image .... 132

Figure 6.9 5-level thresholded image of Lena........................................... 133

Figure 6.10 Flowchart of the search procedure for multi-level thresholding. ... 135

Figure 6.11 5-level thresholded submarine images by the proposed method and Pun’s method ................................................................. 137

Figure 6.12 Fuzzy partition in 5-level thresholding for the submarine image . 138

Figure 6.13 5-level thresholded monument images by the proposed method and Pun’s method ................................................................. 140

Figure 6.14 Fuzzy partition in 5-level thresholding for the monument image .. 141

Figure 6.15 Binary boy image with the proposed method and Pun’s method ... 142

Figure 6.16 5-level thresholded father-and-son images by the proposed method and Pun’s method ................................................................. 144

Figure 6.17 Fuzzy partition in 5-level thresholding for the father-and-son image ................................................................. 145

Figure 6.18 2, 3 and 5-level thresholded lady image .................................. 147
Figure 6.19  Fuzzy partition in 5-level thresholding for the lady image .......... 148
Figure 6.20  2, 3 and 5-level thresholded athlete image ...................... 149
Figure 6.21  Fuzzy partition in 5-level thresholding of the athlete image ...... 150
Figure 7.1   Quadtree image and the new histogram of a fingerprint image .... 159
Figure 7.2   Multiresolution vs. global thresholding on the fingerprint image .. 166
Figure 7.3   Multi-resolution thresholding of a building image .............. 167
Figure 7.4   Multi-resolution thresholding of a baby image ................. 168
Figure 7.5   Multi-resolution thresholding of a lady image ................. 169
Figure 7.6   Multi-resolution thresholding of a signature image ........... 171
Figure 8.1   Color image vs gray scale image................................. 174
Figure 8.2   Color images used for the test .................................... 175
Figure 8.3   Example of the fuzzy 2-partition on a color image ............... 177
Figure 8.4   Thresholded color images with Fuzzy-2 partition................ 178
Figure 8.5   Thresholded color images with Fuzzy-3 partition ............... 178
Figure 8.6   Experiment result with the adaptive color image thresholding method. ............................................................................ 181
List of Tables

Table 5.1 Searching time using the proposed method and the simulated annealing algorithm ................................................................. 110

Table 6.1 Comparasion between the proposed method and Pun’s method . . . 144

Table 7.1 Percentage of the black pixels in the segmented image by different methods ................................................................. 169