

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

Navel Orange Blemish Identification for Quality Grading System

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Computer Science
at Massey University, Albany, New Zealand

MingHui Liu

2009

Abstract

Each year, the world's top orange producers output millions of oranges for human consumption. This production is projected to grow by as much as 64 million in 2010 and so the demand for fast, low-cost and precise automated orange fruit grading systems is only deemed to become more increasingly important.

There is however an underlying limit to most orange blemish detection algorithms. Most existing statistical-based, structural-based, model-based and transform-based orange blemish detection algorithms are plagued by the following problem: any pixels in an image of an orange having about the same magnitudes for the red, green and blue channels will almost always be classified as belonging to the same category (either a blemish or not). This however presents a big problem as the RGB components of the pixels corresponding to blemishes are very similar to pixels near the boundary of an orange. In light of this problem, this research utilizes a priori knowledge of the local intensity variations observed on rounded convex objects to classify the ambiguous pixels correctly. The algorithm has the effect of peeling-off layers of the orange skin according to gradations of the intensity. Therefore, any abrupt discontinuities detected along successive layers would significantly help identifying skin blemishes more accurately. A commercial-grade fruit inspection and distribution system was used to collect 170 navel orange images. Of these images, 100 were manually classified as good oranges by human inspection and the rest are blemished ones. We demonstrate the efficacy of the algorithm using these images as the benchmarking test set. Our results show that the system garnered 96% correctly classified good oranges and 97% correctly classified blemished oranges. The proposed system is easily customizable as it does not require any training. The fruit quality bands can be adjusted to meet the requirements set by the market standards by specifying an agreeable percentage of blemishes for each band.

Acknowledgments

There are three persons I would like to thank for their contributions towards their works.

- **Dr. Napoleon Reyes (Supervisor)**
- **Dr. Andre Barczak (Co-Supervisor)**
- **Mr. Gadi Ben-Tal (Co-Supervisor), Senior Vision Engineer, Compac Sorting Equipment Limited, Auckland, New Zealand**

Thank you for introducing me this interesting topic. Thanks for giving me this opportunity to work on this project. Thanks for the time you spend with me. Many Thanks.

Finally, I will give many thanks to Massey University and all computer science staff. Thank you for providing me the opportunity and resources to work on my project.

Many thanks.

Table of Contents

Title page

Abstract

Acknowledgments

Chapter 1 Research Description	1
1.1 Overview of the Current State of Technology.....	1
1.2 Research Objectives.....	4
1.3 Research Methodology.....	4
1.4 Scope and Limitations of Research.....	5
1.5 Benchmarking Testbed.....	5
1.6 Structure of the Thesis Documentation.....	6
Chapter 2 Theoretical Framework	8
2.1 Advanced Image Processing Techniques.....	8
2.1.1 Otsu’s Method.....	8
2.1.1.1 Overview.....	8
2.1.1.2 General Algorithm.....	10
2.1.2 Canny Edge Detection.....	12
2.1.3 Morphological Operators.....	13
2.1.3.1 Overview.....	13
2.1.3.2 Convex Hull.....	15
2.2 Colour Space.....	16
2.2.1 Overview.....	16
2.2.2 RGB Colour Space.....	17
2.3 Parallel Image Processing System.....	18
2.3.1 Overview.....	18
2.3.2 System Architecture.....	19
Chapter 3 Review of Related Literature	21
3.1 High Speed Vision-Based Quality Grading of Oranges.....	21
3.1.1 Overview.....	21

3.1.2	Image Capture and Processing.....	22
3.1.3	General Algorithms.....	23
3.1.3.1	Histogram Analysis.....	23
3.1.3.2	Local Defect Search.....	24
3.1.3.3	Stem Detection.....	26
3.1.4	System Performance.....	26
3.2	Citrus Fruit External Defect Classification.....	28
3.2.1	Overview.....	28
3.2.2	Wavelet Packet Texture Analysis.....	29
3.2.3	Neural Network Classifier.....	31
3.2.4	System Performance.....	32
3.3	Intelligent Fruit Sorting System.....	34
3.3.1	Overview.....	34
3.3.2	Feature Extraction.....	36
3.3.3	Colour Ratio Judgment.....	37
3.3.4	Naive Bayes Classifier.....	39
3.3.5	System Performance.....	39
3.4	Neural Network-Based Apple Grading.....	40
3.4.1	Overview.....	40
3.4.2	Defect Segmentation.....	41
3.4.3	Neural Network Classifier.....	43
3.4.4	System Performance.....	44
Chapter 4	Preliminary Explorations.....	46
4.1	Otsu's Method.....	46
4.1.1	Experiment and Analysis.....	46
4.1.2	Algorithm Refinements.....	50
4.1.3	Summary.....	52
4.2	High Speed Vision-Based Quality Grading of Oranges.....	53
4.2.1	Histogram Analysis.....	53
4.2.1.1	Algorithm Details with Sample Computations.....	53

4.2.1.2	Neural Network Classifier.....	55
4.2.1.3	Performance.....	56
4.2.1.4	Algorithm Refinements.....	57
4.2.2	Local Defect Search.....	58
4.2.2.1	Algorithm Details with Sample Computations.....	58
4.2.2.2	Neural Network Classifier.....	59
4.2.2.3	Performance.....	59
4.2.3	Overall Quality Grading System Assessment.....	60
4.3	Citrus Fruit External Defect Classification.....	62
4.3.1	Algorithm Details with Sample Computations.....	62
4.3.2	Neural Network Classifier.....	63
4.3.3	Overall Citrus Fruit Defect Classification System Assessment.....	64
Chapter 5	Novel Algorithms on Orange Grading System.....	66
5.1	Central Thesis.....	66
5.2	System Architecture.....	67
5.3	Ripe/Unripe Orange Classification.....	68
5.4	Blemish Detection.....	69
5.4.1	Orange Colour Class.....	69
5.4.1.1	Colour Space Exploration.....	69
5.4.1.2	Derived Formula.....	71
5.4.1.3	General Algorithm.....	72
5.4.1.4	Missing Orange Colour Class.....	74
5.4.1.5	The Order of Orange Colour Classes.....	75
5.4.1.6	Summary.....	75
5.4.2	Orange Class Mean.....	76
5.4.2.1	Overview.....	76
5.4.2.2	General Algorithm.....	76
5.4.2.3	Algorithm Refinements.....	77
5.4.2.4	Effects of Illumination Intensity Variations on Ripe Orange Skin.....	78

5.4.2.5	Effects of Illumination Intensity Variations on Unripe Orange Skin.....	80
5.4.2.6	Summary.....	82
5.4.3	Orange Class Standard Deviation.....	82
5.4.3.1	Overview.....	82
5.4.3.2	General Algorithm.....	83
5.4.3.3	Summary.....	84
5.4.4	Between-Class Squared Mean Difference.....	84
5.4.4.1	Overview.....	84
5.4.4.2	General Algorithm.....	85
5.4.4.3	Summary.....	86
5.4.5	Closest Neighbor Class.....	87
5.4.5.1	Overview.....	87
5.4.5.2	Mean Selection for skewed Distributions.....	87
5.4.5.3	General Algorithm.....	90
5.4.5.4	Closest Neighbor for Ripe and Unripe Oranges.....	91
5.4.5.5	Summary.....	92
5.4.6	Class Reclassification.....	92
5.4.6.1	Overview.....	92
5.4.6.2	Colour Components and Brightness.....	93
5.4.6.3	General Algorithm.....	94
5.4.6.4	Summary.....	95
5.4.7	Pixel Reclassification.....	96
5.4.7.1	Overview.....	96
5.4.7.2	Data Analysis.....	96
5.4.7.3	General Algorithm.....	97
5.4.7.4	Summary.....	98
5.4.8	Blemish Identification.....	98
5.4.8.1	Overview.....	98
5.4.8.2	Topmost Layer Slicing.....	98

5.4.8.3	Blemish Segmentation.....	99
5.4.8.4	Refinement of Blemish Segmentation.....	99
5.4.8.5	Sample Execution of Blemish Segmentation.....	100
5.4.8.6	Experiment and Analysis on Ripe Oranges.....	102
5.4.8.7	Experiment and Analysis on Unripe Oranges.....	105
5.5	Stem Detection and Removal.....	107
5.6	Blemish Quantification.....	109
5.7	Grading.....	110
Chapter 6	Conclusion and Future Work.....	115
Appendix A.	Otsu’s Method.....	117
Appendix B.	Histogram Analysis.....	123
Appendix C.	Local Defect Search.....	125
Appendix D.	Pixel Reclassification.....	127
References.....		128

List of Figures

Fig. 1. Commercial fruit grading system.....	6
Fig. 2. Object segmentation using a constant threshold value.....	9
Fig. 3. Four and eight connectivity.....	14
Fig. 4. Expand, shrink, close and open	14
Fig. 5. Shrink a region to its skeleton.....	14
Fig. 6. Original image.....	15
Fig. 7. Convex image.....	15
Fig. 8. Sealed holes.....	16
Fig. 9. RGB and CMYK color model.....	16
Fig. 10. Example of RGB color space.....	17
Fig. 11. Colour channel splitting of a full RGB colour image.....	18
Fig. 12. Parallel image processing system.....	19
Fig. 13. Example of Zernike masks.....	26
Fig. 14. Processed orange images using high speed vision-based algorithm.....	27
Fig. 15. Citrus fruit external defect classification process.....	29
Fig. 16. Decomposition filter bank structure.....	30
Fig. 17. Neural network classifier for defect classification.....	31
Fig. 18. Colour image processing based intelligent fruit sorting system.....	34
Fig. 19. Vision inspection system in fruit sorting system.....	35
Fig. 20. Result of fruit segmentation using a constant threshold.....	36
Fig. 21. Result of noise removal using blob algorithm.....	37
Fig. 22. Interpolation-based contour detection.....	37
Fig. 23. Hue colour feature distribution.....	38
Fig. 24. Result of searching red pixels in an image.....	38
Fig. 25. BL, GR, RE, and IR filter images.....	40
Fig. 26. “Jonagold” apple samples.....	41
Fig. 27. Stem removal using neural network-based apple grading algorithm.....	42

Fig. 28. Example of segmentation using neural network.....	44
Fig. 29. Ripe orange sample for testing Otsu's method.....	46
Fig. 30. Isolated colour channels for ripe orange sample.....	46
Fig. 31. Example of ripe orange segmentation using Otsu's method.....	47
Fig. 32. Blemished ripe orange sample for testing Otsu's method.....	47
Fig. 33. Example of blemished ripe orange segmentation using Otsu's method.....	48
Fig. 34. Unripe orange sample for testing Otsu's method.....	48
Fig. 35. Isolated colour channels for unripe orange sample.....	48
Fig. 36. Example of unripe orange segmentation using Otsu's method.....	48
Fig. 37. Blemished unripe orange sample for testing Otsu's method.....	49
Fig. 38. Example of blemished unripe orange segmentation using Otsu's method.....	49
Fig. 39. Orange segmentation on the red channel using a constant threshold value fifty.....	50
Fig. 40. True and false positive rates using a constant threshold value fifty.....	51
Fig. 41. True and false positive rates using a constant threshold value seventy.....	51
Fig. 42. Example of scaled histogram.....	53
Fig. 43. Probability density at each gray level.....	54
Fig. 44. Example of image preprocessing.....	57
Fig. 45. Sample regions selected with a typical size of 30x30.....	58
Fig. 46. System workflow.....	61
Fig. 47. Sample image before and after preprocessing.....	63
Fig. 48. Example of decomposition resulting to 16 sub-windows.....	63
Fig. 49. Blemish detection based on a specified local intensity variation range.....	67
Fig. 50. Block schematic of the novel orange grading algorithm.....	67
Fig. 51. Ripe and unripe oranges.....	68
Fig. 52. Orange classification for ripe and unripe oranges.....	69
Fig. 53. A representation of additive colour mixing.....	70

Fig. 54. Colour component window in Paint.net.....	70
Fig. 55. Predefined orange colour classes.....	71
Fig. 56. Example of ripe orange image with two blue lines drawing across the center.....	78
Fig. 57. Intensity variations along the vertical blue line.....	79
Fig. 58. Two pixels selected from normal and blemished skin separately.....	79
Fig. 59. Example of unripe orange image with two red lines drawing across the center.....	80
Fig. 60. Intensity variations along the vertical red line.....	81
Fig. 61. Three pixels selected from the normal and blemished skin separately.....	81
Fig. 62. Similarity of the orange colour classes.....	87
Fig. 63. Demonstration of the closest neighbor class.....	87
Fig. 64. Clusters.....	94
Fig. 65. Image generated using the pixel reclassification matrix.....	98
Fig. 66. Segment the blemished area on the very top layer.....	99
Fig. 67. Spots in the segmented image.....	100
Fig. 68. Segmented image before and after the erode operation.....	100
Fig. 69. Blemish identification results for ripe oranges.....	100
Fig. 70. Blemish identification results for blemished ripe oranges.....	101
Fig. 71. Blemish identification results for unripe oranges.....	101
Fig. 72. Blemish identification results for blemished unripe oranges.....	102
Fig. 73. Result of image processing for a good ripe orange.....	102
Fig. 74. True positive rates computed based on one hundred good ripe oranges.....	103
Fig. 75. Result of image processing for a blemished ripe orange.....	103
Fig. 76. Blemish identification testing for blemished ripe orange.....	104
Fig. 77. True and false positive rates plotted for seventy blemished ripe oranges.....	104

Fig. 78. Blemishes identified outside of the topmost layer.....	105
Fig. 79. Some blemishes are hard to detect by human eye.....	105
Fig. 80. Example of skin colour variation on an unripe orange.....	106
Fig. 81. Result of merging the top two layers.....	106
Fig. 82. True positive rates computed based on sixty good oranges.....	106
Fig. 83. Intensity variation for blemished unripe oranges.....	107
Fig. 84. Blemish identification with different positions.....	107
Fig. 85. Intensity variation among three selected pixels.....	108
Fig. 86. Stem detection using Otsu's method.....	108
Fig. 87. Blemishes misclassified as the stem.....	108
Fig. 88. Depth of the blemish.....	108
Fig. 89. Classification results before smoothing the rough edges.....	110
Fig. 90. Classification results after smoothing the rough edges.....	111
Fig. 91. Classification results after removing the stem.....	112
Fig. 92. Classification results using the new formula.....	113
Fig. 93. Histogram analysis for Otsu's method implementation.....	118
Fig. 94. Probability analysis for Otsu's method implementation.....	118

List of Tables

Table 1. Vision-based algorithm classification result.....	27
Table 2. Citrus fruit external defect classification result.....	33
Table 3. Part of the citrus fruit classification results with images.....	34
Table 4. Classification result of intelligent fruit sorting system.....	40
Table 5. Result of classification using neural network-based grading algorithm.....	44
Table 6. Result of implementing histogram-based analysis.....	56
Table 7. Result of implementing modified histogram-based analysis.....	58
Table 8. Result of implementing modified local defect search.....	60
Table 9. Result of implementing improved vision-based grading algorithm.....	62
Table 10. Result of implementing external defect classification algorithm.....	65
Table 11. Orange colour class classification.....	71
Table 12. Orange class distribution matrix with detailed analysis.....	73
Table 13. Example of the orange class distribution matrix.....	74
Table 14. Orange colour class availability test for ripe oranges in the database.....	74
Table 15. Example of the orange class mean matrix.....	77
Table 16. Intensity variations along the horizontal blue line.....	78
Table 17. Intensity variations along the horizontal red line.....	80
Table 18. Example of the statistical analysis matrix.....	83
Table 19. Statistical analysis matrix with computed between-class variances.....	85
Table 20. Example of the covariance matrix.....	86
Table 21. Example of four different means.....	89
Table 22. Example of the computation for quadratic means.....	90
Table 23. Example of finding the closest neighbor class.....	91
Table 24. Example of the orange class mean matrix for a ripe orange.....	91
Table 25. Example of the orange class mean matrix for an unripe orange.....	91
Table 26. Example of the closest neighbor array with specified class numbers.....	92
Table 27. Class reclassification.....	93

Table 28. Example of the new class mean matrix for demonstration purpose.....	96
Table 29. Summary of classification results using the novel algorithm.....	114
Table 30. Sample data selected for Otsu's method implementation.....	117
Table 31. Sample data selected for image preprocessing.....	123
Table 32. New class mean matrix for demonstration purpose.....	127