UNIVERSITI PUTRA MALAYSIA

NEAR-INFRARED TECHNIQUE FOR OIL PALM FRUIT GRADING SYSTEM

OSAMA MOHAMED BEN SAEED

FK 2013 24
NEAR-INFRINGEMENT FOR OIL PALM FRUIT GRADING SYSTEM

By

OSAMA MOHAMED BEN SAEED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

November 2013
COPYRIGHT

All material contained within the thesis, including without limitation text, logos, icons, photographs and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia
DEDICATION

To My Mother

To My Father, My Brothers, My Sisters, My Wife Zinib, My Children Mohamed, Ala, AndAnass For Their Moral Support And Encouragement.
NEAR-INFRARED TECHNIQUE FOR OIL PALM FRUIT GRADING SYSTEM

By

OSAMA MOHAMED BEN SAEED

November 2013

Chairman : Associate Professor Abdul Rashid Bin Mohamed Shariff, PhD
Faculty : Engineering

The Malaysian palm oil industry is considered to be highly regulated. A major problem faced by oil palm producers is the accurate grading of fresh oil palm fruits according to their ripeness levels before processing. Classification of oil palm fresh fruit bunch (FFB) maturity is a critical factor that dictates the quality of produced palm oil. The human eye, for example, has historically judged quality via appearances. External features and properties such as color, texture, shape, and size are good indicators for parameters like ripeness. Hence, grading system technologies offer a solution to these problems. The grading systems in general utilized improved engineering designs with image processing techniques to ensure the quality of the product. In this research, a hyperspectral oil palm grading system was built and an image processing techniques algorithm was developed based on the spectral reflectance of the external features of oil palm fresh fruit bunches (FFB). Color changes resulting from biochemical reactions in fruit texture can be related to fruit maturity. In addition, the oil palm fruit pigments such as carotenoids and chlorophylls and their ratios affect the color of the oil palm fruit. Underripe fruits have a higher proportion of chlorophyll that gradually decreases upon maturity. Similarly, carotenoids increase as the oil palm fruits mature. These color and biochemical changes can be observed utilizing the spectral reflectance of the fruit. Using the FFB spectral reflectance this research was used to modify and adapt the hyperspectral scanner to enhance its suitability for the maturity detection of oil palm FFBs at the near-infrared (NIR) range (400 nm to 1000 nm). This objective was achieved by improving the illumination system of the hyperspectral scanner. The strategic positioning of the halogen and applied security design (ASD) lamps helps provide a shadow for free illumination. Image processing approaches, such as image acquisition, image pre-processing, and image feature extraction, as well as image classification were developed to automate the ripeness grading for oil palm fruit bunches. The mathematical model was developed to determine the real value of the
reflection of specific wavelengths for the three categories of oil palm FFBs through regression analysis. The results are then confirmed by a trained human grader. The application software was developed in a MATLAB 7.0 environment, and was used to classify the oil palm FFBs. The data collected by this system are subjected to the artificial neural networks (ANN), kernel nearest neighbor (KNN), support vector machine (SVM) techniques, and a number of statistical analyses such as the CHAID method and one-way ANOVA for oil palm FFB classification. The developed system showed high classification results on accuracy of the maturity detection for the three types of oil palm fruits (nigrescens, virescens, and oleifera) with rates of 95%, 99%, and 98%, respectively, using the ANN-MLP classifier; rates of 96%, 99%, and 98%, respectively, using the KNN classifier; and rates of 76%, 96%, and 94%, respectively, using SVM. Based on the results of testing hyperspectral with the scientific results of bands of overripe, underripe, and ripe we fabricated the multiband sensor. This multiband active sensor has the ability to detect the maturity of oil palm fruit at 735, 750, 780, and 940 nm). The multiband sensor was field tested and can categorize the oil palm FFB into three classes: overripe, ripe, and underripe. The system helps increase the accuracy of the oil palm FFB grading system, which will be useful for the oil palm industry, oil palm engineers, mill operators, plantation managers, small holders, and the research community.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PENDEKATAN TEKNIK INFRA MERAH UNTUK SISTEM PENGGREDAN BUAH KELAPA SAWIT

Oleh

OSAMA MOHAMED BEN SAEED

November 2013

Pengerusi : Professor Madya Abdul Rashid bin Mohamed Shariff, PhD
Fakulti : Kejuruteraan

sawit melalui analisis regresi. Keputusan kemudiannya disahkan oleh pegawai penggred yang terlatih. Perisian aplikasi telah dibangunkan menggunakan persekitaran MATLAB versi 7.0, dan telah digunakan untuk menguraikan ciri-ciri BTS kelapa sawit. Data yang dikumpul oleh sistem ini telah diolah di dalam rangkaian neural tiruan (ANN), kernel jiran terdekat (KNN), mesin vektor sokongan teknik (SVM), dan beberapa analisis statistik seperti kaedah CHAID dan ANOVA sehala untuk klasifikasi BTS kelapa sawit. Sistem yang telah diuji ini menunjukkan hasil pengelasan tinggi pada ketepatan pengesanan matang bagi tiga jenis buah kelapa sawit (nigrescens, virescens, dan oleifera) dengan kejitan 95%, 99%, dan 98% masing-masing, dengan menggunakan pengelasan ANN - MLP; kadar 96%, 99%, dan 98% masing-masing, dengan menggunakan pengelas KNN; dan kadar sebanyak 76%, 96%, dan 94%, masing-masing, dengan menggunakan pengelas SVM. Berdasarkan keputusan ujian Hiperspektra yang saintifik, kumpulan-kumpulan BTS terlalu masak, kurang masak, dan masak telah dapat dikenali pasti. Sebuah penderia aktif pelbagai jalur direkacipta menggunakan prinsip kajian ini. Penderia ini mempunyai keupayaan untuk mengesan kematangan buah kelapa sawit di tahap gelombang (735, 750, 780, dan 940 nm). Sensor pelbagai jalur ini telah diuji dilapangan dan boleh mengkategorikan BTS kelapa sawit kepada tiga kelas: terlalu masak, masak, dan kurang masak. Sistem ini dapat membantu meningkatkan ketepatan sistem penggredan BTS kelapa sawit, yang akan berguna untuk industri kelapa sawit, jurutera pertanian, operator kilang, pengurus ladang, pekebun kecil, dan komuniti penyelidikan.
AKNOWLEDGEMENTS

All praise and thanks are due to the Name of Allah, Most Gracious and Most Merciful. May peace and blessings be upon His Messenger. I would also like to express the most sincere appreciation to those who made this work possible: advisory members, friends, and family.

I would like to thank Assoc. Prof. Dr. Abdul Rashid Mohamed Shariff for providing me the opportunity to complete my PhD studies under his valuable guidance, for the useful advice and discussions, for his constant encouragement and guidance, and for co-authoring and reviewing a number of my publications, where his practical experience and technical knowledge made this research and those publications more interesting and relevant. In addition, I would also wish to extend special thanks to the supervisory committee members: Assoc. Prof. Dr. A. R. Mahmud, Assoc. Prof Dr. H. Z. Mohd. I owe my deepest gratitude to Dr. M. D. B. Amiruddin from Malaysian Palm Oil Board (MPOB) for his very helpful advice and guidance. I am grateful for their willingness to serve on my supervisory committee as well as for their constant encouragement, helpful advice, and many fruitful discussions.

Engineering Academy Tajoura, Libya is gratefully acknowledged for providing financial support. The support of the academy, and its management under the leadership of its Abdul Rashid Mohamed Shariff helped me meet my financial obligations while staying in Malaysia.

Thanks and acknowledgements are meaningless if not extended to my parents who deserve my deepest appreciation. I am grateful for the countless sacrifices they made to ensure that I could pursue my dreams and for always being there for me. Real and deepest thanks to them. May Allah bless and protect them and may they live a long and healthy life. All praises and words of thanks will not be enough.

Last but not least, very special thanks to my wife, daughter, sons, my family in Libya for their support, love, and encouragement, which comprise the foundation of my success.
I certify that a Thesis Examination Committee has met on 28 November 2013 to conduct the final examination of Meftah Salem M. Alfatni on his PhD thesis entitled "Near-Infrared Technique for Oil Palm Fruit Grading System " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

**Zulkifly bin Abbas, PhD**
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

**Ishak bin Aris, PhD**
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

**Siti Khairunnizabinti Bejo, PhD**
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

**Atsushi Hashimoto, PhD**
Professor
Mie University Putra Malaysia
Japan
(External Examiner)

---

**NORITAH OMAR, PhD**
Associate Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 19 May 2014
This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as partial fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

**Abdul Rashid Mohamed Shariff, PhD**  
Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Ahmad Rodzi Bin Mahmud, PhD**  
Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Helmi Zulhaidi Bin Mohd, PhD**  
Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Mohd Din Amiruddin, PhD**  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**BUJANG BIN KIM HUAT, PhD**  
Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:
Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vic-Chancellor (Research and Innovation) before thesis is published (in the form written, printed or in electronic form) including books, journals, modules, proceeding, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification / fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: __________________ Date: __________________
Name and Matric No: _______________________________
Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and writing of this thesis was under supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ____________________  Signature: ____________________
Name of Chairman of Supervisory Committee: ____________________
Name of Member of Supervisory Committee: ____________________
Name of Member of Supervisory Committee: ____________________
Name of Member of Supervisory Committee: ____________________
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEDICATION</td>
<td>ii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>iii</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>v</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>vii</td>
</tr>
<tr>
<td>APPROVAL</td>
<td>viii</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xiv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xvi</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xx</td>
</tr>
</tbody>
</table>

## CHAPTER

1 INTRODUCTION
---

1.1 Background 1
1.2 Problem Statement 2
1.3 Objectives of the research 3
1.4 Scope of the Research 4
1.5 Thesis Layout 4

2 LITERATURE REVIEW
---

2.1 Introduction 5
2.2 Oil Palm Background 6
2.3 Characteristics of Palm Oil 7
   2.3.1 Hybrid of E. oleifera 7
   2.3.2 Hybrid of E. Guineensis 8
2.4 Nondestructive Techniques to Ensure Quality and Safety of Fresh Product 9
   2.4.1 Quality and Safety Assurance of Fresh Product 9
2.5 Near-Infrared (NIR) and Mid-Infrared (MIR) Technology 10
   2.5.1 Typical Applications of NIR Spectroscopy 10
   2.5.2 NIR Technology in Vegetables and Fruits 12
   2.5.3 MIR Spectrum and Imaging Applications 14
2.6 Machine Vision System 14
   2.6.1 Background 14
   2.6.2 Machine Vision System as a Controlled System 15
2.7 Application of Remote Sensing in Vegetation 15
2.8 Hyperspectral Remote Sensing and its Contribution to Fruit Assessment 20
2.9 Applications of Hyperspectral Remote Sensing for the Determination of Fruit Maturity 21
2.10 Optimal Band Selection and Combination Problem  25
2.11 Direct Comparison   26
   2.11.1 ANN   26
   2.11.2 KNN   27
   2.11.3 SVM   28
   2.11.4 SPSS Classification Tree  30
       2.11.4.1 CHAID Method  30
2.12 Summary   30

3 FRESH FRUIT BUNCH (FFB) HYPERSONTAL SCANNER  32
   3.1 Introduction   32
   3.2 Modification and Adaptation of Hyperspectral Camera  32
   3.3 Study Area   34
   3.4 Methodology of Oil Palm Fruit Bunch Grading System  34
       3.4.1 Data Preparation and Analysis  38
       3.4.2 Hyperspectral Image Acquisition  42
           3.4.2.1 Sensor Camera  44
           3.4.2.2 Illumination  45
           3.4.2.3 Sampling Unit  46
           3.4.2.4 Setting the System  47
           3.4.2.5 Using the Normalization Tool  52
       3.4.3 Image Processing  55
           3.4.3.1 Background Removal  56
           3.4.3.2 Noise Removal  57
           3.4.3.3 Dimension Deduction  57
           3.4.3.4 Band Image Extraction  58
       3.4.4 Classification System  60
           3.4.4.1 Receiver Operating Characteristic (ROC)  66
           3.4.4.2 Area under ROC curve (AUC)  67
   3.5 Classification Generation Model (Regression Analysis)  68
       3.5.1 Residuals Have Constant Variance (Homoscedasticity)  69
       3.5.2 Independence of Residuals  70
       3.5.3 Normality of Residuals  70
       3.5.4 Linearity  70
   3.6 Results of Hyperspectral System  70
       3.6.1 Introduction  70
       3.6.2 Data Preparation  72
       3.6.3 Spectral Reflectance of the Nigrescens Fruit  72
       3.6.4 Spectral Reflectance of the Virescens Fruit  73
       3.6.5 Spectral Reflectance of the Oleifera Fruit  74
       3.6.6 Spectral Reflectance based on Data for All Fruit Types
           (Nigrescens, Virescens, and Oleifera)  75
       3.6.7 ANN-MLP, KNN, and SVM Evaluation Using Receiver
           Operating Characteristic  76
           3.6.7.1 Optimal Neural Network Classifier Results  76
           3.6.7.2 Optimal KNN Classifier Results  78