UNIVERSITI PUTRA MALAYSIA

REAL-TIME OIL PALM FRUIT BUNCH RIPENESS GRADING SYSTEM USING IMAGE PROCESSING TECHNIQUES

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By

MEFTAH SALEM M. ALFATNI

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

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DEDICATION

To whom their true love and support were behind my success, to my father, my mother, my brothers, my sisters, my wife, my Daughters, my sons and my friends.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of requirement for the degree of doctor of philosophy

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Supervisor: Assoc. Prof. Abdul Rashid Mohamed Shariff, PhD
Faculty: Engineering

Fruits and other agriculture products are valued by their appearance, which is a major factor in the judgment of quality. The human eye, for example, has historically judged quality via appearances. External features and properties such as colour, texture, shape, and size are good indicators for parameters like ripeness and defects. Grading varies among graders and is often inconsistent. The adaptation of human eye to small changes in colour and the effect of the background on the perceived colour and intensity are the main sources of error. 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 real time oil palm grading system was built and an image processing techniques algorithm was developed based on the external features of oil palm fresh fruit bunches (FFB) such as colour, texture, and thorns. The purpose of which was to investigate the relationship between the external features and ripeness of different oil palm FFB types as well as to test and validate the implementation of oil palm grading system methods and techniques. Special grading system with specific methods and techniques was built with fast, accurate, and objective ripeness classification to work with the parameters and properties of oil palm FFB, which is important for the farmers to have an objective classifier before selling their product as well as the oil palm companies to classify correctly the quality of oil palm fruit bunches due to the variations in different oil palm qualities.

Image processing approaches, such as acquisition, pre-processing, segmentation, feature extraction, and classification as well as expert rule-based system, were developed to automate the ripeness grading for oil palm fruit bunches. Feature extraction for oil palm FFB colour, texture, and thorns was implemented by using statistical colour features, colour histogram, grey-level co-occurrence matrices (GLCM), basic grey level aura matrix technique (BGLAM), and Gabor wavelet techniques on the three different regions of interest (ROIs), namely, ROI1, ROI2, and ROI3. These ROIs were based on the training and the testing of the ANN, KNN, and SVM supervised machine-learning classifiers. Statistical measurements, such as

the area under the receiver operating characteristic (ROC) curve (AUC), are used to evaluate classifier performance.

The performance results showed that BGLAM, which was based on the ANN classifier and applied on the ROI3, was the optimal technique for grading oil palm FFB types with 93% performance accuracy and a 0.44 second processing speed. Furthermore, the grading system graded the oil palm FFB ripeness based on three different models. First, a significant 93% performance accuracy and a 1.6 second processing speed were achieved by combining the colour histogram and the ANN classifier applied on ROI3 based on the Nigrescens and Oleifera colour model. A 1.4 second processing time was achieved when the combination was applied on ROI2 for the Virescens colour model. Second, BGLAM and ANN applied on ROI3 achieved 92% accuracy and a 0.43 second processing time for the Nigrescens texture model. BGLAM and ANN achieved 93% accuracy applied on the ROI2 with a 0.40 second processing time for the Oleifera and Virescens texture models, which are the optimal results based on the texture model. Third, GLCM and ANN applied on the ROI1 achieved 87% accuracy and a 3.7 second processing time for the Nigrescens thorns model, whereas BGLAM applied on the ROI3 based on SVM achieved 91% accuracy and a 1.20 second processing time for the Oleifera thorns model as well as 88% accuracy and a 0.83 second processing time for the Virescens colour model. These results are optimal based on the thorns model. A new approach was developed using expert rules-based system. This system is based on three different ROIs that showed the best rule-based results, and were selected for further testing stages. For example, the rule-based ROIs for statistical color feature extraction with KNN classifier at 94% were chosen. The ROIs that indicated results higher than the rule-based outcome, such as the ROIs of statistical color feature extraction with ANN classifier at 94%, were used for further FFB ripeness testing.

The results show that the texture models gives the best alogrithm result for oil palm FFB types and ripeness classification, where the BGLAM based on ANN with ROI3 gives a high accuracy 93% with shorter image processing time 0.44 (s) for FFB type recognition, whereas the alogrithm of BGLAM based on ANN and ROI3 with accuracy 92% and short processing time 0.43 (s) for Nigrescens, as well as the alogrithm of BGLAM based on ANN and ROI2 with accuracy 93% and short processing time 0.40 (s) for Oleifera and Virescens. The best rule-based and ROIs results were selected for further testing stages. This research has achieved its stated goal of developing a real time oil palm grading system for automated FFB types and ripeness classification. This system will be useful to the oil palm plantations in Malaysia and the rest of the oil-palm growing world. The results will benefit oil palm engineers, mills, managers, small holders, and enforcement agencies.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SISTEM PENGGREDAN BUAH KELAPA SAWIT SEGAR MASA SEBENAR MENGGUNAKAN TEKNIK PENPROSESAN IMEJ

Oleh

MEFTAH SALEM M. ALFATNI

Disember 2013

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

Penilaian buah-buahan dan produk-produk pertanian dari luar bentuknya merupakan faktor utama dalam penilaian kualiti. Sebagai contohnya, mata manusia menilai kualiti melalui luar bentuk sejak dahulu lagi. Ciri-ciri dan sifat-sifat luaran buah-buahan seperti warna, tekstur, bentuk dan saiz adalah petunjuk yang baik bagi parameter seperti kematangan dan kecacatannya. Terwujud perbezaan dalam penggredan antara penggred-penggred dan ia selalunya juga tidak konsisten. Penyesuaian mata manusia untuk perubahan kecil dalam warna dan kesan latar belakang pada warna yang dilihat serta intensitinya merupakan sebab-sebab utama bagi kesilapannya. Oleh itu, teknologi sistem penggredan menawarkan langkah penyelesaian kepada masalah-masalah ini. Secara umumnya, sistem penggredan menggunakan reka bentuk kejuruteraan dengan teknik pemprosesan imej untuk memastikan kualiti produk. Dalam kajian ini, sistem penggredan kelapa sawit secara masa sebenar telah dibina dan teknik pemprosesan imej beralgoritma telah dibentuk dengan berdasarkan ciri-ciri luaran buah kelapa sawit yang bertandan (FFB) seperti warna, tekstur, dan duri. Tujuan adalah untuk mengkaji hubungan antara ciri-ciri luaran dan kematangan kelapa sawit berjenis FFB serta menguji dan mengesahkan pelaksanaan kaedah sistem penggredan dan teknik kelapa sawit. Sistem penggredan khas dengan kaedah dan teknik yang tertentu telah dibina dengan cepat, tepat, dan klasifikasi kematangan yang berobjektif untuk mengkaji parameter dan sifat-sifat kelapa sawit FFB yang merupakan suatu yang penting bagi para petani untuk mempunyai pengelasan yang berobjektif sebelum menjual produk mereka serta penting juga untuk syarikat-syarikat kelapa sawit untuk mengklasifikasikan dengan betul bagi kualiti tandan buah kelapa sawit yang disebabkan oleh variasi-variasi kualiti kelapa sawit yang berbeza.

Pendekatan-pendekatan pemprosesan imej seperti pengambilalihan imej, pra-pemprosesan imej, segmentasi imej, ekstrakasi ciri-ciri imej, dan klasifikasi imej serta sistem pakar pengasasi peraturan yang berkepakaran telah dilaksanakan untuk mengautomasikan penggredan kematangan tandan buah kelapa sawit. Pengekstrakan ciri-ciri warna kelapa sawit FFB, tekstur, dan duri telah dilaksanakan dengan menggunakan ciri-ciri warna secara statistik, warna histogram, grey-level co-occurrence matrices (GLCM), basic grey level aura matrix technique (BGLAM), dan Gabor wavelet techniques di tiga berlainan kawasan yang berminat (ROIs), iaitu

ROI1, ROI2, dan ROI3. ROI ini adalah berdasarkan kepada latihan dan ujian ANN, KNN, dan SVM pengklasifikasi mesin-belajar yang diselia. Ukuran statistik seperti kawasan dalam receiver operating characteristic (ROC) curve (AUC) adalah digunakan untuk menilai prestasi pengklasifikasi.

Keputusan prestasi menunjukkan bahawa BGLAM yang berdasarkan pada klasifikasi ANN yang diaplikasikannya pada ROI3 adalah teknik yang optimum untuk penggredan kelapa sawit berjenis FFB dengan ketepatan prestasi sebanyak 93% dan kelajuan pemprosesan 0.44 saat. Tambahan pula, sistem penggredan menggredkan kematangan kelapa sawit FFB berdasarkan tiga model yang berbeza. Pertama, ketepatan prestasi yang bersignifikan pada 93% dan kelajuan pemprosesan 1.6 saat telah dicapai dengan menggabungkan warna histogram dan pengklasifikasi ANN yang digunakan pada ROI3 dengan berdasarkan warna model Nigrescens dan Oleifera. Pemprosesan masa 1.4 saat telah dicapai apabila gabungan itu diapplikasikan pada ROI2 untuk warna model Virescens. Kedua, pengapplikasi BGLAM dan ANN pada ROI3 mencapai ketepatan 92% dan masa pemprosesan 0.43 saat bagi model tekstur Nigrescens. BGLAM dan ANN mencapai ketepatan 93% yang mengapplikasikan pada ROI2 dengan 0.40 saat pemprosesan masa bagi Oleifera dan model-model tekstur Virescens, merupakan keputusan yang optimum berdasarkan model tekstur. Ketiga, GLCM dan ANN yang mengaplikasikan pada ROI1 mencapai ketepatan 87% dan pemprosesan masa 3.7 saat bagi model Nigrescens berduri, manakala BGLAM mengaplikasikan pada ROI3 dengan berdasarkan SVM mencapai ketepatan 91% dan pemprosesan masa 1.20 saat bagi model Oleifera berduri serta ketepatan 88% dan pemprosesan masa 0.83 saat bagi warna model Virescens. Keputusan-keputusan ini adalah optimum dengan berdasarkan model pendurian.

Satu pendekatan baru telah dibangunkan di bawah nama expert rules-based system. Sistem ini adalah berdasarkan pada tiga berlainan ROI yang menunjukkan keputusan yang terbaik dengan berasaskan peraturan, dan juga terpilih untuk peringkat-peringkat ujian yang selanjutnya. Sebagai contoh, ROI yang berasaskan peraturan untuk pengekstrakan ciri warna secara statistik dengan pengklasifikasi KNN pada 94% telah dipilih. ROI menunjukkan keputusan yang lebih tinggi daripada hasil yang berasaskan peraturan, seperti ROI pengekstrakan ciri warna secara statistik dengan pengklasifikasi ANN pada 94%, telah digunakan untuk ujian kematangan FFB selanjutnya. Keputusan menunjukkan model-model tekstur memberikan hasilan yang terbaik untuk kelapa sawit berjenis FFB dan juga klasifikasi kematangannya, di mana BGLAM yang berdasarkan ANN dengan ROI3 memberikan ketepatan yang tinggi sebanyak 93% dengan masa pemprosesan imej yang lebih pendek, iaitu 0.44 (s) untuk pengiktirafan jenis FFB, manakala BGLAM yang berdasarkan ANN dan ROI3 dengan ketepatan 92% dan masa pemprosesan 0.43 (s) untuk Nigrescens, serta BGLAM berdasarkan ANN dan ROI2 dengan ketepatan 93% dan masa pemprosesan 0.40 (s) untuk Oleifera dan Virescens. Keputusan peraturan-berasaskan yang terbaik dan keputusan-keputusan ROI telah dipilih untuk ujian berperingkat yang selanjutnya. Kajian ini telah mencapai matlamat yang dinyatakan, iaitu melaksanakan masa sebenar sistem penggredan kelapa sawit untuk automotif yang berjenis FFB dan juga klasifikasi terhadap kematangannya. Sistem ini berguna kepada ladang-ladang kelapa sawit di Malaysia dan juga negara-negara yang mempunyai penanaman minyak sawit. Keputusan ini akan memanfaatkan jurutera

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My journey as a student has come to an end with the completion of this thesis. Many people have shared my best and worst moment during the past few years. I would like to thank them all.

I certify that a Thesis Examination Committee has met on 9 December 2013 to conduct the final examination of Meftah Salem M. Alfatni on his PhD thesis entitled "Real-Time Oil Palm Fruit Bunch Ripeness Grading System Using Image Processing Techniques" in accordance with the Unversities 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:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment on the requirement for the degree of Doctor of Philosophy. The members of the supervisory committee are as follows:

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