UNIVERSITI PUTRA MALAYSIA

IDENTIFICATION OF BASAL STEM ROT DISEASE IN OIL PALM TREE USING THERMAL IMAGING TECHNIQUE

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By

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

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August 2018

Chairman : Siti Khairunniza Bejo, PhD
Faculty : Engineering

Basal stem rot (BSR), caused by *Ganoderma boninense* is known as one of the deadliest diseases in the oil palm plantations in Southeast Asia. *Ganoderma* could reduce the productivity of oil palm plantations and possibly reduce the market value of palm oil in Malaysia. The available technique of BSR detection is time-consuming and human dependence. This study focuses on detecting the oil palm tree infected by BSR using thermal imaging technique. In order to find a suitable time to capture the thermal images, thermal images of canopy and trunk sections of the oil palm trees from healthy and BSR-infected trees were captured in the morning (9 to 12 pm) and afternoon (12 to 3 pm) session. The images were pre-processed using FLIR QuickReport 1.2 (FLIR Systems, Inc., Oregon, United States). The images were then processed using MATLAB software (Version R2016b, The MathWorks Inc., Massachusetts, United States) to extract pixel value representing thermal properties of the trees. After that, statistical analysis was done using these pixel values. The result from T-test has shown that thermal images taken at canopy section during the afternoon session have a significant difference ($\alpha<0.05$) between healthy and BSR-infected trees. There were four features extracted from the images of canopy section namely minimum, maximum, mean and standard deviation value. Based on the statistical analysis, only mean of the pixel value gave a significant difference with a P value of 0.0052. For the maximum feature, all the data has the same value regardless of the healthiness condition, hence this feature will not be used for further analysis. Four different types of classifier namely, Linear Discriminant Analysis (LDA), Quadratic Discriminant Analysis (QDA), Support Vector Machine (SVM) and k-nearest neighbour (kNN) were used and compared. Input parameters were taken from different combinations of the features to classify the healthy and BSR-infected trees. The result showed that quadratic SVM with the input parameter using a combination of minimum and mean gave the highest percentage of accuracy with 67.0%. In order to improve the accuracy, new indices called; healthy variance (Y_H) BSR-infected variance (Y_{UH}) and all variance (Y_{ALL}) were developed based on the squared value of the difference between the mean intensity value of an oil palm tree and the averaged mean intensity value of healthy, BSR-infected and all samples accordingly. However, it only gave the best accuracy at 62.3% from the combination of minimum, mean, standard deviation and Y_{UH} using linear SVM classifier. As a result, the Principal Component Analysis (PCA) was introduced to extract the most suitable features among six features available. The score plot of PC1 versus PC3 has shown that there were two distinguishable trendlines where the BSR-infected tree is located outside the trendline of the healthy trees. Values of PC1 and PC3 were later used for classification using all fourteen different types of classification model. Based on the results, the quadratic SVM model gave the best classification with the highest accuracy of 89.2% for the training set and 84.4% for the test set. Based on this study, it can be concluded that thermal imaging has the potential for BSR detection in oil palm trees.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

MENGENALPASTI PENYAKIT REPUT PANGKAL BATANG PADA POKOK KELAPA SAWIT MENGGUNAKAN TEKNIK PENGIMEJAN TERMA

Oleh

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Reput pangkal batang (RPB) adalah sejenis penyakit yang disebabkan oleh sejenis fungus, *Ganoderma boninense*. Ia dikenali sebagai penyakit paling berbahaya di ladang kelapa sawit sekitar Asia Tenggara. *Ganoderma* boleh mengurangkan kadar produktiviti ladang kelapa sawit dan juga berpotensi mengurangkan nilai pasaran minyak sawit di Malaysia. Teknik pengesanan RPB sedia ada memerlukan masa yang lama dan terlalu bergantung dengan tenaga kerja manusia. Kajian ini menumpukan pengenalpastian sifat terma pokok yang sihat dan yang dijangkiti penyakit RPB menggunakan teknik pengimejan terma. Bagi mendapatkan masa yang sesuai untuk mengambil imej terma, imej terma pada bahagian kanopi dan batang pokok kelapa sawit telah diambil daripada pokok yang sihat dan pokok yang dijangkiti RPB ketika sesi pagi (9 hingga 12 pm) dan sesi petang (12 hingga 3 pm). Imej terma tersebut telah dipra-proses menggunakan perisian FLIR QuickReport 1.2 (FLIR Systems, Inc., Oregon, United States) dan kemudiannya diproses menggunakan perisian MATLAB (Versi R2016b, The MathWorks Inc., Massachusetts, United States) untuk mengestrak nilai piksel yang mewakili sifat terma pokok. Selepas itu, analisis statistik dilakukan menggunakan nilai tersebut. Hasil daripada ujian-T menunjukkan imej terma yang diambil pada bahagian kanopi ketika sesi petang mempunyai perbezaan yang signifikan ($\alpha<0.05$) antara pokok yang sihat dan dijangkiti RPB. Terdapat empat sifat yang disari daripada imej pada bahagian kanopi iaitu nilai minimum, maksimum, purata dan sisihan piawai. Hasil daripada analisis statistik, hanya purata nilai piksel yang memberikan perbezaan signifikan dengan nilai P sebanyak 0.0052. Bagi nilai maksimum pula, kesemua data mempunyai nilai yang sama walaupun berbeza keadaan kesihatan. Oleh itu, sifat ini tidak akan digunakan untuk analisis seterusnya. Empat belas jenis model pengelasan yang berbeza iaitu Analisis Pembeza Layan Linear (LDA), Analisis Pembeza Layan Kuadratik (QDA), Mesin Vektor Sokongan (SVM) dan Jiran Terhampir-k (kNN) digunakan dan dibandingkan. Parameter input daripada gabungan sifat yang berbeza telah digunakan untuk mengelaskan pokok yang sihat dan dijangkiti RPB. Keputusan menunjukkan SVM kuadratik dengan gabungan sifat minimum dan purata telah menghasilkan peratus ketepatan tertinggi dengan nilai 67.0%. Bagi mempertingkatkan ketepatan pengelasan, indeks baru yang dikenali sebagai variasi sihat (Y_H), variasi jangkitan RPB (Y_{UH}) dan variasi kesemuaya (Y_{ALL}) telah dihasilkan berdasarkan nilai kuasa dua perbezaan purata pokok dengan purata kesemua pokok yang dikira berdasarkan sampel pokok yang diambil daripada pokok yang sihat, dijangkiti RPB dan gabungan kedua-duanya. Walau bagaimanapun, ia hanya memberikan peratus ketepatan tertinggi pada 62.3% sahaja daripada gabungan sifat minimum, purata, sisihan piawai dan indeks Y_{UH} melalui pengelas SVM linear. Hasilnya, AKP telah digunakan untuk mengekstrak sifat yang paling sesuai di antara enam sifat yang ada. Plot skor PC1 versus PC3 telah menunjukkan bahawa ada dua garis arah aliran yang boleh dibezakan di mana pokok yang dijangkiti RPB terletak di luar garis arah aliran pokok yang sihat. Nilai PC1 dan PC3 kemudiannya digunakan untuk pengelasan menggunakan empat pengelas berbeza. Hasil keputusan menunjukkan pengelas SVM kuadratik memberi peratus ketepatan tertinggi dengan nilai 89.2% untuk set latihan dan 84.4% untuk set ujian. Berdasarkan kajian ini, dapat disimpulkan bahawa teknik pengimejan terma mempunyai potensi untuk mengenalpasti jangkitan RPB pada pokok kelapa sawit.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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- the research conducted and the writing of this thesis was under our supervision;
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CHAPTER 1

INTRODUCTION

1.1 General Overview

Oil palm is one of the most important crops in Malaysia. In 2016, the agriculture sector stood at 8.1% or RM89.5 billion to the Gross Domestic Product (GDP). Oil palm was a major contributor to the GDP of agriculture sector at 43.1% followed by other agriculture (19.5%), livestock (11.6%), fishing (11.5%), forestry & logging (7.2%) and rubber (7.1%) (Department of Statistics Malaysia, 2017). Malaysia is one of the top producers and exporters of the palm oil globally, producing 103.96 million tonnes of oil palm fresh fruit bunch in 2017 (Economics and Industry Development Division, 2018).

Oil palms have an extensive range of products and applications in both food and non-food sector. Its multi-purpose property makes oil palm industry high in demand. The potential productivity of oil palm is several times greater than the other oil-producing crops, given that the crop is managed appropriately, much less land is required to produce the same amount of vegetable oil compared with other vegetable oil crops (Donough et al., 2009).

However, the oil palm tree in Malaysia is no exception to disease. Among other diseases, a fungal disease caused by *Ganoderma boninense*, known as basal stem rot (BSR) leads to great losses in oil palm production. BSR is notorious as one of the most destructive diseases at oil palm tree in plantations around Southeast Asia, particularly in Malaysia and North Sumatra (Flood et al., 2000). It attacks the basal stem of oil palm trees making them rot and slowly affecting xylem of the trees and causing water transportation to the upper part of oil palm become disturbed, thus the leaves at the oil palm's frond turn yellow. It is a major threat to the palm oil industry as it can reduce the yield of oil palm, hence causing economic losses to oil palm plantations (Kamu et al., 2016).

Different treatment methods were invented to treat BSR infection. Among the common methods used in controlling BSR infection are fungicide treatment (George et al., 1996) and biological control (Sapak et al., 2006). Another common method used in treating BSR-infected oil palm trees is by removing the infected oil palms and mounding the soil around the tree or a mixture of these two methods (Darus & Abu Seman, 2002). However, none of the methods mentioned is completely adequate in stopping and minimizing the effects of the disease on the yield production as well as the health of the trees (Singh, 1991). Some plantations purposely leave the trees without any treatment to reduce the treatment cost, causing the yield production to reduce over time.

It was found that the existing treatments for BSR infection were not completely efficient in treating the oil palm trees in the later stages of infection. Therefore, detection of BSR infection is needed in order to treat the trees as soon as possible before the infection in oil palm plantation becomes worse. Currently, there are three approaches to detect BSR; manual, laboratory-based and remote sensing method. The manual observation is the most common technique to detect BSR. It was done by detecting the *Ganoderma* specific foliar symptoms and fungus fruiting bodies which grow as a parasite on the trunks. However, it requires a labour force with the knowledge to identify BSR-infected trees and differentiate other unhealthy trees due to different causes. It is also time-consuming as the oil palm trees are needed to be observed carefully and closely to check for the symptom one by one.

For laboratory-based approaches, the test sample is extracted by drilling the trunk of the oil palm tree. Ganoderma Selective Medium (GSM) test and Polymerase chain reaction (PCR) analysis are done using the extracted samples for the isolation, growth and identification of the fungus in the samples (Lim & Fong, 2005). The diagnostics method used are usually difficult to do due to its complex procedures. Some of the methods are also considered as expensive because of the cost needed to provide all necessary components for the analysis (Lelong et al., 2010; Wahab et al., 2011).

Non-invasive remote sensing based approaches have also been explored in order to identify and map the BSR-infected trees using different techniques such as ground-based, airborne and space-borne remote sensing. Hyperspectral and multispectral remote sensing approaches had shown the capability of identifying healthy and BSR-infected trees from recent studies (Khairunniza-Bejo et al., 2015; Mohamad Anuar et al., 2015). Terrestrial Laser Scanning (TLS) (Khairunniza-Bejo & Vong, 2014), Intelligent Electronic Nose (E-Nose) system (Abdullah et al., 2012; Azahar et al., 2011), tomographic sensor (Hamidon & Mukhlisin, 2014) and Microfocus X-ray Fluorescence (µXRF) (Meor Yusoff et al., 2009) also showed positive results in detecting BSR-infected tree. These reports showed that the techniques used are capable of early detection of BSR and differentiating the healthy and BSR-infected trees. However, some of the approaches were still limited to further classify the severity level of BSR infection (Khosrokhani et al., 2016).

Thermal imaging is a method of detecting infrared radiation of an object represented by an image. All objects with a temperature greater than absolute zero (-273°C) emit infrared radiation, however, human's vision is limited to visible spectrum electromagnetic radiation. Thermal imaging extends human's limited vision beyond the boundary to view the infrared radiation. Thermal imaging has been used in various applications in different industries such as detecting moisture and building failure, including leaks. It is also used in medical field to detect peripheral vascular disorders (Bagavathiappan et al., 2009), to aid in detecting breast cancer (Arora et al., 2008) and to assist in detecting bone fracture injury (Cook et al., 2005). For agricultural industry, it is used to determine the plant physiological state and irrigation scheduling (Jones, 2004) and yield forecasting (Smith et al., 1985; Stajnko et al., 2004). Water stress in sunflower leaves can also be analysed from thermal image processing system (Hashimoto et al., 1984). It was also employed in detecting infestation by *Cryptolestes ferrugineus* inside wheat kernels (Manickavasagan et al., 2008) and to evaluate the damage to fruits and vegetables due to microbial activities (Hellebrand et al., 2002). Sankaran et al. (2013) used a combination of visible, near infrared and thermal imaging techniques to detect citrus greening disease in citrus trees. Based on the literature, it can be concluded that thermal imaging was able to analyse the water stress of plants as well as detecting disease. As BSR infection affected the water transportation of oil palm, the water stress of the BSR infected tree will vary from the healthy tree. Therefore, there is a potential use of thermal imaging in detecting BSR infection.

1.2 Problem Statement

A variety of study and approach has been explored for the detection of BSR disease in oil palm trees including manual visual inspection, laboratory analysis and remote sensing. The capability of these techniques to detect BSR in oil palm tree is still limited in term of the labour force, cost and time. It is also noted that some approaches still have a limitation in detecting BSR infection at the early stage.

Thermal imaging has been used in agricultural applications for disease detection and water stress analysis. Previous studies showed a good potential of using thermal imaging in detecting oil palm tree infected by BSR as BSR infection also affected the water stress of the oil palm tree. However, up to recently, the study on detecting the infected BSR tree in palm oil plantation using thermal imaging is still a largely unexplored research area to date. This research will explore and evaluate the potential of thermal imaging in detecting BSR at oil palm trees.

1.3 Objectives

The goal of this research is to explore the potential of using thermal imaging to identify oil palm trees infected with Basal Stem Rot (BSR) disease. Specific objectives are:

i. To identify the suitable time and tree section for thermal image acquisition.
ii. To identify the suitable features to differentiate healthy and BSR-infected trees extracted from thermal images.
iii. To classify BSR-infected trees using machine learning techniques.

1.4 The Scope of the Study

This study explored the potential of using thermal images to detect BSR disease at matured oil palm trees. The healthiness status of the trees was classified by the expert from Malaysian Palm Oil Board (MPOB). Therefore, the differences of the tree condition were assumed due to *Ganoderma boninense* infection, not by other factors. The emissivity of the thermal camera was fixed to 0.98 to ensure all the images are in the same condition. This study was focused on analysing the variation of thermal in intensity, not in detecting the temperature of the trees.

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