OPTIMIZED FEATURE SELECTION FOR TROPICAL WOOD SPECIES RECOGNITION USING GENETIC ALGORITHM

USWAH BINTI KHAIRUDDIN

UNIVERSITI TEKNOLOGI MALAYSIA

OPTIMIZED FEATURE SELECTION FOR TROPICAL WOOD SPECIES RECOGNITION USING GENETIC ALGORITHM

USWAH BINTI KHAIRUDDIN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

OCTOBER 2012

To my beloved husband and son

ACKNOWLEDGEMENTS

In the name of Allah, Most Gracious and Most Merciful

I would like to express my sincerest appreciation to my supervisor, Prof. Datin Dr. Rubiyah Yusof for her guidance, encouragement and advices. I am very thankful to her for her patience in correcting my mistakes and helping me achieve this master's degree successfully. I look up to her as a great mentor, a great researcher and a great life motivator. My sincerest thanks go to all great researchers and friends in Centre for Artificial Intelligence & Robotics (CAIRO), especially Puan Nenny Ruthfalydia Rosli, for helping me throughout my master's journey. Support given from all of you keeps me motivated to finish this master's project. Finally, I would like to thank my parents and beloved husband, Zayd for their patience and support which helped me went through difficult times. Thank you very much to all of you.

ABSTRACT

An automatic tropical wood species recognition system was developed at the Centre for Artificial Intelligence & Robotics (CAIRO), Universiti Teknologi Malaysia. The system classifies wood species by using texture analysis whereby wood surfaces images are captured and the features are extracted from these images which are then used for classifications. The system uses Grey Level Co-occurrence Matrix (GLCM) feature extractor and Back Propagation Neural Network (BPNN) classifier and it can classify 20 wood species. The system performs well with over 90% accuracy. However, when more wood species are added for classification, the accuracy was reduced significantly due to enormous variations among wood. In this thesis, feature selection algorithm by wrapper Genetic Algorithm (GA) was added into the system to overcome features redundancy, making the within class features less discriminatory while increasing the discriminatory features of inter class variations. Basic Grey Level Aura Matrices (BGLAM) and Structural Properties of Pores Distribution (SPPD) feature extractors are used instead of GLCM and the classifiers used are k-Nearest Neighbour and Linear classifiers in Linear Discriminant Analysis (LDA). Results of experiments before and after feature selection for all databases are compared and analysed. The feature selection algorithm shows a considerable improvement in the classification accuracy from 86% to 95%. A new mutation operation in the GA for feature selection is also developed to increase the GA convergence rate while maintaining its level of performance.

ABSTRAK

Sebuah sistem mengenal spesies kayu tropika automatik telah dibangunkan di Pusat Kecerdikan Buatan dan Robotik (CAIRO), Universiti Teknologi Malaysia. Sistem ini membuat pengelasan spesies kayu menggunakan analisis tekstur dimana gambar pelbagai imej permukaan kayu dirakam dan ciri-ciri diekstrak dari imej-imej ini sebelum digunakan untuk pengelasan. Sistem ini menggunakan pengekstrak ciri Matrik Kejadian Bersama Aras Kelabu (GLCM) dan pengelas Rangkaian Neural Perambatan Ke Belakang (BPNN) dan ia mampu mengklasifikasi 20 spesies kayu. Sistem ini mempunyai prestasi yang baik iaitu melebihi 90% ketepatan. Walau bagaimanapun, peratusan ketepatan didapati jatuh dengan banyak apabila lebih banyak spesies kayu ditambah kerana terdapat banyak variasi diantara spesies kayu. Di dalam tesis ini, algoritma pemilih ciri menggunakan Pembungkus Algoritma Genetik (GA) telah ditambah ke dalam sistem bagi mengatasi pertindihan ciri dan mengurangkan perbezaan ciri di dalam kelas dalam masa yang sama meningkatkan ciri unik di antara kelas. Pengesktrak ciri Matrik Aura Aras Kelabu Asas (BGLAM) dan Sifat Struktur Taburan Leliang (SPPD) digunakan bagi menggantikan GLCM dan pengklasifikasi yang digunakan adalah Kejiranan Terdekat-k and pengelas linear dalam Analisis Diskriminan Lelurus (LDA). Keputusan eksperimen sebelum dan selepas proses pemilihan ciri untuk keseluruhan data dibanding dan dianalisa. Algoritma pemilihan ciri menunjukkan peningkatan yang besar dalam ketepatan pengelasan dari 86% ke 95%. Operasi mutasi baru dalam GA bagi pemilihan ciri juga dibangunkan bagi meningkatkan kadar penumpuan GA tanpa mengurangkan tahap prestasinya.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia is one of the top exporters for tropical timbers product in the world. Statistics from Malaysian Timber Industry Board (MTIB) shows that timber exports contributed more than 4.5 billion USD for the country's 2011 income. Tropical timbers are used in various activities and industries around the world. Revenues are generated from housing or development industries, furniture and shipping industry. It is important for the timber dealers to generate such revenue for future import-export activities. To do so, they have to maintain the quality of timber products, ensure the exact type of timber being used for certain products and ensure the exact type of timber being exported all around the world. However, some timber exporter practices fraudulent labeling to escape from paying high amount of export tax (Ruhong Li, 2008). Therefore, there are quite number of cases where wrong types of timber are used for the end product. This problem will cause danger especially in the development and housing industries.

Illegal logging is also one of the issues faced by timber exporting countries such as Malaysia. Some of the activities related to illegal logging are fraudulent labeling, illegal harvest of the timbers, illegal timber processing, import and export of illegal timbers. There are many negative environmental effects from illegal logging. Exotic birds are in the danger of being extinct as they have lost their habitat in the tropical forests (Chapman, *et al*., 2001 & Johns, 1996). Wood species diversity will also be reduced due to the widespread illegal logging without any control and law enforcement. There are more than 32 million hectares of tropical forests damaged each year resulting in a loss of more than 360 million USD annual tax (Casson & Obidzinski, 2002). Income of people in money-poor, resource-rich countries is reduced because illegal trading of timbers. Fraudulent labeling also reduces country's revenues generated by tax and tariffs where high quality wood are labeled as low quality and will be imposed a lower tax. It is important to have a good system that can control these kinds of activities.

In 4-weathered countries like United States, European countries and Japan, there are wood atlases where all images and details of wood types are compiled and become reference (Hoadley, 1990). They compare an unknown wood species with descriptions and illustrations in wood atlases in order to make wood identification. The identification process is simple and easy because wood types in these countries are of softwood type only and there are only 12 species of softwood altogether. However, wood identification process in Tropical climate countries are more complicated because of the large number of tropical wood species, mostly hardwoods which have many variations.

1.2 Manual Wood Recognition

There are more than 3000 tropical wood species in Malaysian woods, in which only 12 of them are softwoods (Menon, 1993). Wood species are usually recognized by the physical appearance of its tree. Some important characteristics to be observed are the shape and smell of leaves, type and colour of flowers and fruits on the tree and the bark, where bark is the outermost layer of the tree trunk.

However, when the trees are felled and processed to timber, these important characteristics are no longer available to present the identity of the wood species.

In order to identify wood species after it was processed to timber, another set of characteristics can be used. They are; the colour of the wood, the weight or density of the wood, the hardness, the smell and lastly, the texture on the wood surface. Menon (1993) has written a book that explained in detail the wood structure and how to identify wood species. The texture is actually the wood grain pattern on the cross section of timber surface. Out of these characteristics, wood texture will play the most important part in wood species identification. The texture will not be changed or evolved even after going through many processes. It will also maintain the same wood grain pattern after any type of chemical procedures. The age and place of growth may give variation to the texture. However, it can still be identified because the texture of wood is like fingerprints to humans. Our fingerprints may change a little as we grow but it remained to be unique to ourselves. It is essential to note that colour of wood may differ according to its location of growth, its age and its moisture. Furthermore, the colour may change after undergone chemical procedures. Chemical procedures will also alter the density, hardness and smell of the wood. Drying process will have the woods burned to remove all the moisture inside the wood. This process may change the wood colour, weight, density and also smell.

The process of identifying wood species by looking at its surface texture can only be done by experts that have years of training. MTIB & Forest Research Institute Malaysia (FRIM) also provides wood identification services done by their experts with some service charges. These experts will look at the wood's surface and examine its macroscopic features. They will then determine the wood type by referring to a dichotomous key for wood surface features. The dichotomous key is similar to a long hierarchical chart that stores information of wood surface features. It is a chain-list containing descriptions on wood grain pattern that will lead to species identification.

The chain list which contains the specific criteria of descriptions that match the pattern has to be followed diligently in order to obtain the matching answer.

Wood texture can be seen on the cross section of timber surface (Figure 1.1) using a special magnifier that can give ten times (10X) magnification. Figure 1.2 shows how manual wood species identification is done using the magnifier and what the person is expected to see through the magnifier.

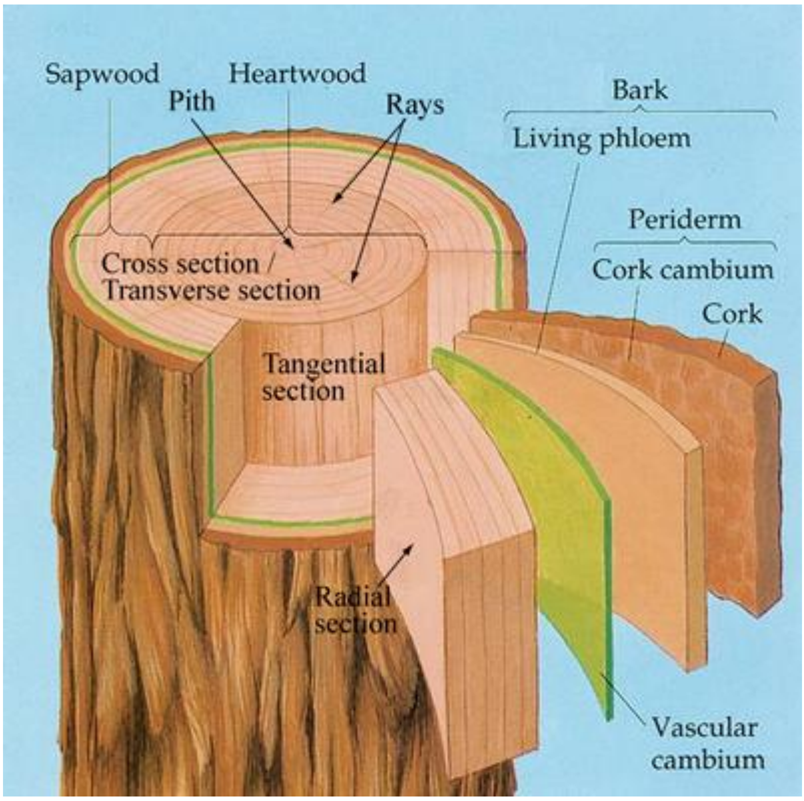

Figure 1.1 : Cross section of a tree trunk (image source: http://www.doitpoms.ac.uk)

Figure 1.2 : Manual identification by human using magnifier (left) and texture surface image through the magnifier lens

Wood surface structure has some unique characteristics that can differentiate one species from the others. Important characteristics that these experts look at are the structure of:

- vessels or pores
- wood parenchyma or soft tissue
- rays or rays parenchyma
- fibers
- phloem
- latex traces
- intercellular canals

Vessels or pores can be seen on the transverse section of wood. It may look like holes on the wood surface. Figure 1.3 shows pores on wood surface. These pores are constructed as a continuous pipe-like to carry food and nutrition through the trees. Different species may have different size, arrangement and number and density of pores in their surface. Some species has deposits in their pores. These characteristics are very important and can become the key identification for wood species.

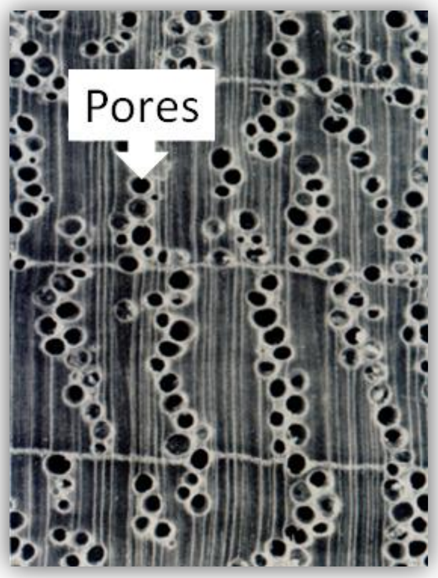

Figure 1.3 : Pores on wood surface

Pores may occur in single, pairs or multiples. Single pores are called solitary pores. Pair pores occur when two pores are so near each other that end walls in contact are flattened and the pores looks like a single pore that have been divided to two. Multiples pores, which are also called scalariform pores occur when multiple pores are crowded and so near each other and it forms a long string of pores. Figure 1.4 below shows example of solitary, pair and scalariform pores.

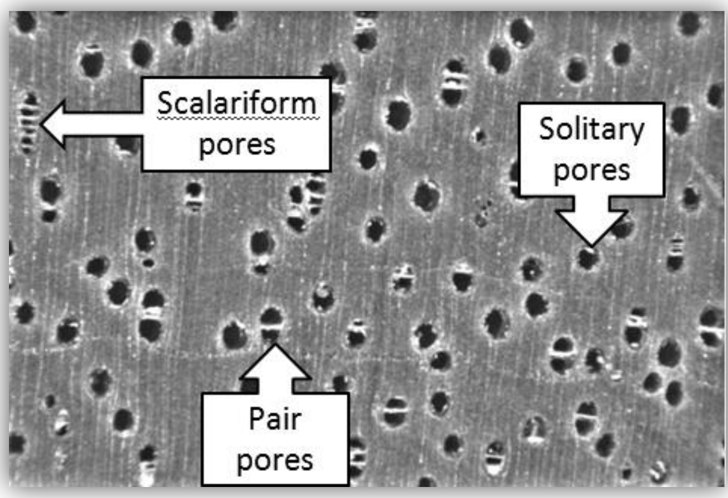

Figure 1.4 : Types of pores arrangement on wood surface

Pore density is determined by how many number of pores available per square millimeters on wood surface. Figure 1.5 below shows wood surface with low pores density and numerous pores density. Some of inactive pores are blocked with gummy or chalky substance called pores deposit. They are actually tyloses which are projected by the wall cavity. Figure 1.6 shows deposits in some pores.

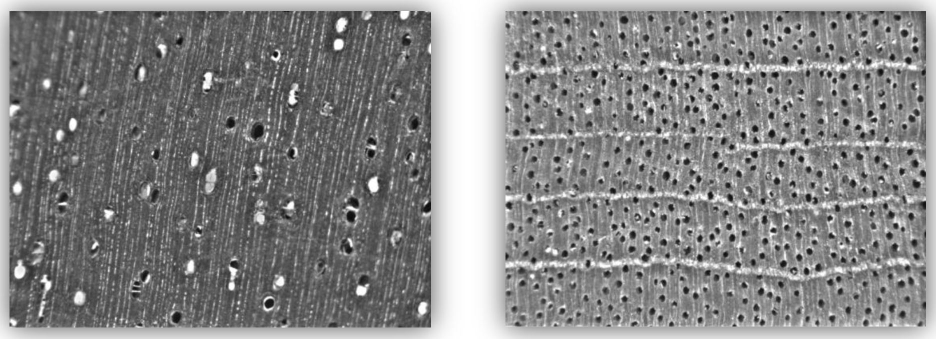

Figure 1.5 : Wood surface with low density (left) and numerous density (right)

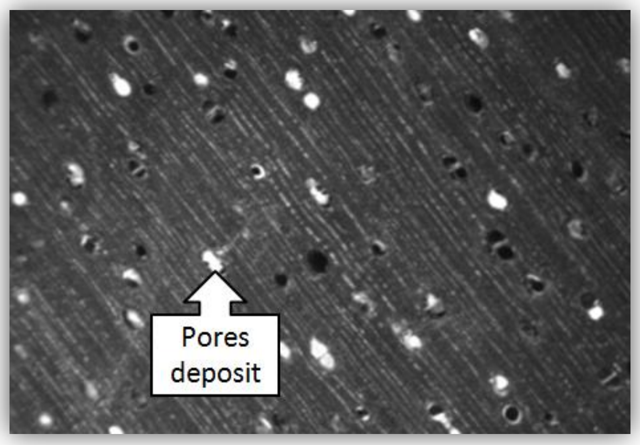

Figure 1.6 : Some of the pores filled with pores deposit

Other important features on wood surfaces are the parenchymas. Parenchymas are wood tissues that used for storage and distribution of reserve food materials. The amount and arrangement of parenchymas are different between wood species. Therefore, the structure of parenchymas may become important information in wood species classification.

Figure 1.7 shows diffuse type parenchymas on wood species Keledang. Diffuse parenchyma is a single parenchyma cells that are distributed irregularly among the fibres.

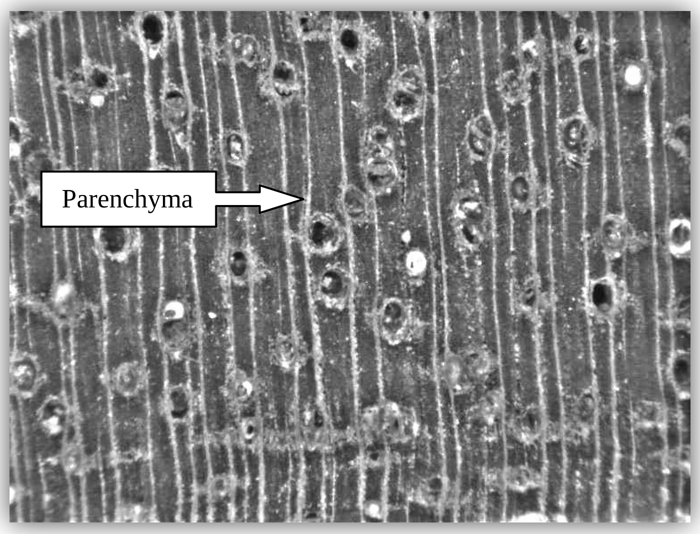

Figure 1.7 : Diffuse parenchymas on Keledang wood surface

Another type of parenchyma is a short tangential lines parenchyma. There are some cells groups that are scattered tangentially between the rays to form network-like lines. Figure 1.8 is an example of short tangential lines parenchyma.

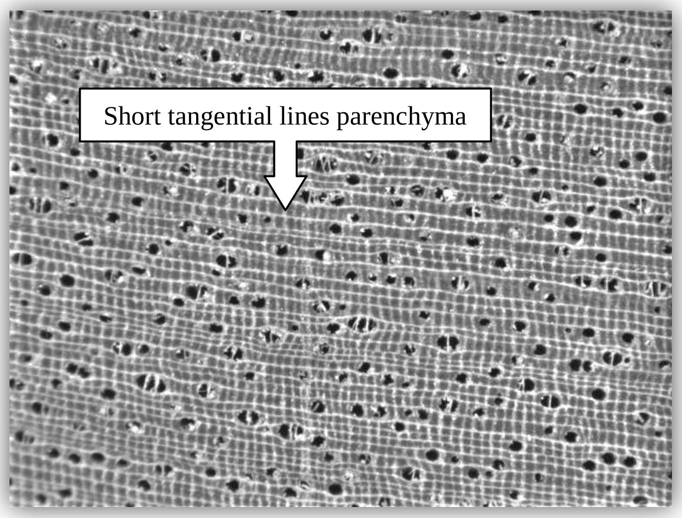

Figure 1.8 : short tangential lines parenchymas on Keranji wood surface

There are also bands or banded parenchyma where the parenchyma rays are so widely spaced than one another. Figure 1.9 shows example of banded parenchyma on mataulat wood surface.

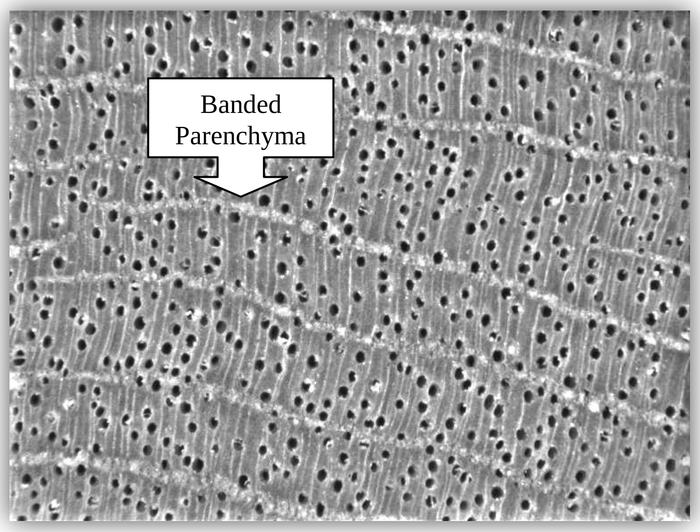

Figure 1.9 : Banded parenchyma on Mataulat wood surface

The diffuse, short tangential lines and banded parenchyma are all from the *apotracheal* group of parenchyma where they are not associated with vessels or pores. Parenchymas that are associated with vessels are from the group *paratracheal* paranchymas. The parenchyma tissues of this group usually found at pores surroundings. Most common *paratracheal* parenchyma is aliform parenchyma where the surroundings parenchyma tissues on the pores extended to form a wings-like shape. Figure 1.10 shows aliform parenchyma on wood species Kempas.

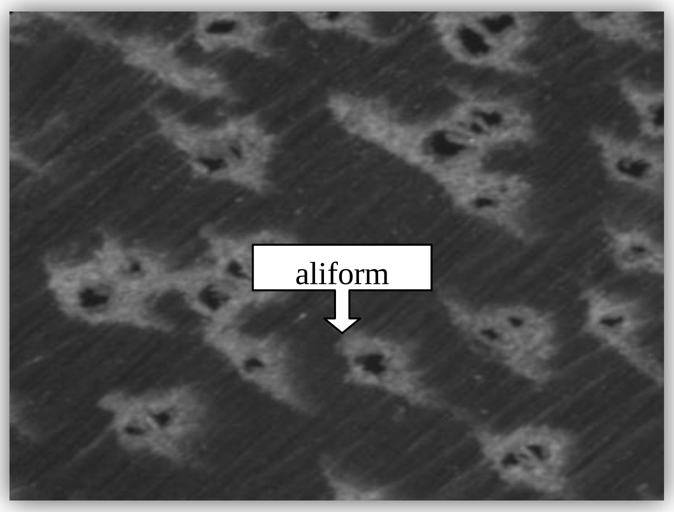

Figure 1.10 : Aliform parenchyma on Kempas wood surface

Other structural features on wood surface such as phloem, latex traces and intercellular canals are rarely seen on any types of wood species. These features are usually assumed as standard marks on wood or defects on wood. In this system, these marks will become noise features that may affect species classification result. An example of resin canal may be seen in Figure 1.11 below.

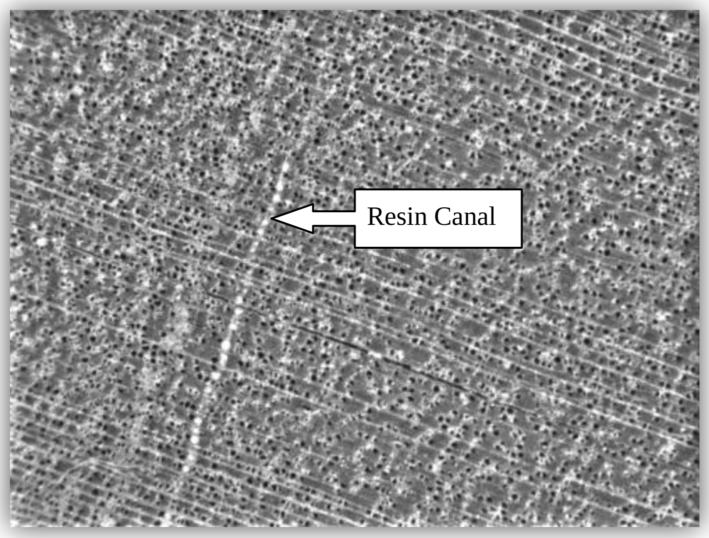

Figure 1.11 : Resin canal on Giam surface

There is no doubt that the structural features discussed above may be the key features in classifying wood species. The most important features are the pores characteristics as it is unique for every species. Therefore, after taking into accounts all these information, a new feature extractor called Statistical Properties of Pores Distribution (SPPD) which extracts all information from pores characteristics; pores size, pores density and types of pores, was developed. This feature extractor will be used in the automatic tropical wood species recognition system alongside other feature extraction methods.

1.3 Automatic Tropical Wood Species Recognition System

There are only a few certified personnel that can identify tropical wood species. Due to the large number of timber trade activities in exporting countries, the use of automatic recognition system is very much needed. In order to simplify the wood identification process and make it available at every timber trade checkpoint such as shops, customs, contractors, Marzuki Khalid *et al.* (2008) have developed an automatic tropical wood texture recognition system based on wood macroscopic features called 'KenalKayu'. The system will automatically identify wood species without the presence of experts. The system mimics the manual wood species recognition system by experts as described in the book by Menon, where they only need to have a look at the wood surface and from the texture pattern and identify the wood species by referring to a dichotomous key. In the automatic tropical wood species recognition system, the experts were replaced by the pattern recognition algorithms processed very fast using computers. A charge-coupled device (CCD) camera with 10 times (10×) magnification captures images of wood surface where the wood grain pattern is visible. The images are stored in a database and classified using pattern classification algorithm.

The work includes the use of grey level co-occurrence matrix (GLCM) technique and Gabor filters for extracting the texture features of the wood species and using multi-layer back propagation neural network (BPNN) for classification. Figure 1.12 below shows the flowchart of the automatic tropical wood species recognition system. However, since the macroscopic anatomy image of wood is not uniform but contains variation of intensities which form certain repeated patterns called visual texture (Petrou & Sevilla, 2006), the system can only indentifies 20 types of tropical wood species. The system's 95% accuracy dropped tremendously when more wood species are added into the database.

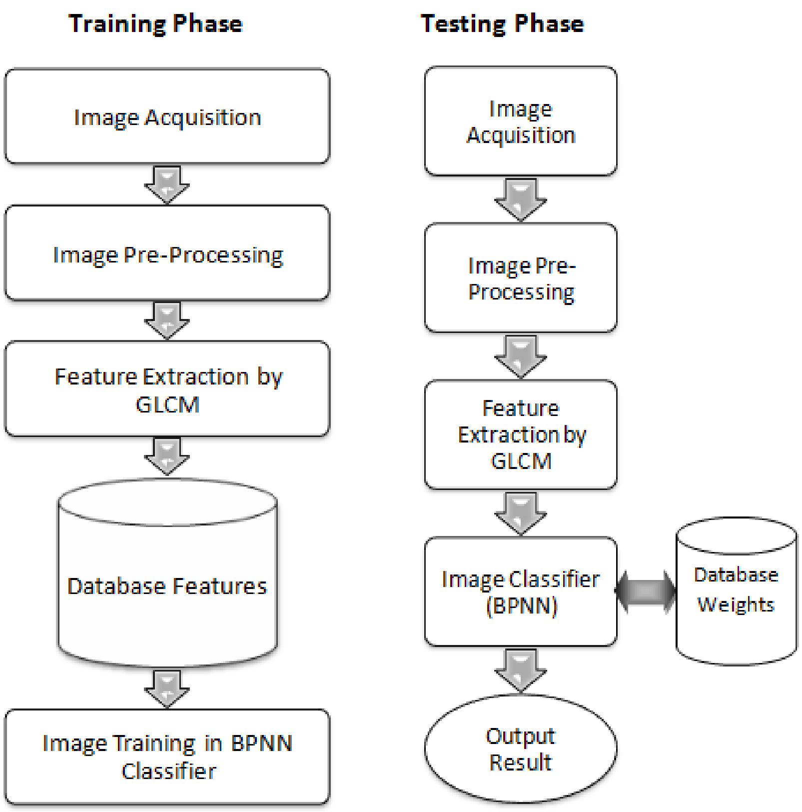

Figure 1.12 : Flow diagram for the automatic tropical wood species recognition system

In order to make the automatic system more robust, new algorithms are needed to cater for larger databases. In this thesis, the use of feature selection algorithms is explored in a way of making the system more accurate for larger databases. Preprocessing techniques such as homomorphic filtering is used as an image pre-processing technique which filters the image after nonlinear mapping into different domain and the image are mapped back into the original domain. This process eliminates illumination and reflectance in the image thus reduces noisy features in it.

Different feature extraction techniques such as the Basic Grey Level Aura Matrix (BGLAM), developed by Xuejie Qin and Yee-Hong Yang (2007) and Statistical Properties of Pores Distribution (SPPD) (Khairuddin, *et al.*, 2011) are also explored in order to provide the system with better features to be used for classifications. The BGLAM feature extraction algorithm is similar to GLCM feature extraction method. However, the process is more straightforward. The numerical combinations of grey level values are taken as BGLAM features directly without going through any additional filters. BGLAM features are more reliable as it is proven that it can re-produce the original image from the feature values.

The SPPD feature extraction mimics manual procedure of tropical wood species recognition which is observing the pores characteristics such as size and density of pores. SPPD features are very important as wood texture is not a simple uniform pattern but contains a lot of variation even in the same wood species. Therefore, SPPD records the key of recognizing wood which is the pores characteristics.

This thesis presents feature-level fusion scheme where two feature datasets obtained using different feature extractors; BGLAM and SPPD, are concatenated into one database. This process is made possible due to the same nature of both feature datasets, and its homogeneity. Although the features are in different range, this problem is easily solved by data normalization to a same specified, small range.

Although increasing number of features will give more information for the data (Solberg & Jain, 1997, Clausi & Huang Deng, 2005 and Bing-Yu Sun, *et al.*, 2010), there are also downsides of it. Some of the features are redundant and not discriminative. Feature redundancies will affect accuracy due to inter class and intra class discriminatory factors. There are also error features that did not give correct information about the image because it is obtained from uncontrolled environment when capturing the images.

Therefore, feature selection algorithm is introduced into the system to solve the above problems. Feature selection is a process that makes subset selection from the original database and it retains original features without changing the features' domain (Huan Liu & Lei Yu, 2005). The feature selection technique is proposed for the implementation of the automatic tropical wood species recognition system in order to improve the system's accuracy. The addition of the feature selection not only able to reduce the size of the wood databases but will have an effect in keeping only important discriminant features for classification use. The process can result in the removal of noise features that originates from wood defect or marks such as latex traces, resin canal and phloem.

Other objectives of feature selection that were highlighted by Liu, et. al. (2005) are:

1) To reduce database dimensionality

   Big dimensions will require more complex computations. Therefore, it is easier to work with smaller dimensions database. Error may be reduced as well.

2) To remove irrelevant features

   Quantity does not determine the quality. More features do not ensure good outcomes. Only good features can give good outcomes. Therefore, the extras, or outliers must be removed from the database.

3) To reduce learning computational cost

   More features will result in high computational time. By reducing the feature dimensions, computational cost will be cut accordingly.

4) To increase variables prediction accuracy

   After feature selection, only discriminative features are kept in the database. These features are unique for each class and can differentiate it with other classes.

5) To keep only important features that gives comprehensive understanding for all variables.

   Every object has its important features that will be its own signature. For example, important key features for human identification are sex, height, skin colour etc. The other not so important features are the size of feet, the length of arm. These features are hard to be distinguished from others.

In this thesis, an optimize feature selection algorithm was developed to the fused feature set by selecting only discriminant features to be used for classification. A wrapper Genetic Algorithm (GA) is introduced into the system to make feature selection and classification.

Feature selection process using wrapper GA may be a lengthy process because it involves repetition of classification process for large sized database. In the automatic tropical wood species recognition system, almost all features database's size is large. Therefore, feature selection process will be time consuming. In order to overcome this problem, a new mutation operation in GA was developed to increase the convergence rate in feature selection process. This new mutation operation is developed in such way to assist feature selection by GA. It creates good feature combinations from high fitted chromosomes thus fasten the process of obtaining the perfect feature combinations.

1.4 Research Objectives

The objectives of this master's project are as follows:

a) To develop a feature selection algorithm using Genetic Algorithm (GA)
b) To implement feature selection algorithm in the automatic tropical wood species recognition system
c) To use suitable feature extraction method that can gives good discriminative features
d) To select suitable classifiers that can work with GA and give the best classification accuracy.
e) To develop method for reducing the computation time of the GA based feature selection

1.5 Study Scope and Limitations

The automatic tropical wood species recognition system is a big ongoing project in CAIRO, UTM. This project is supported by MOSTI with collaboration from FRIM. FRIM owns a wood library that stores almost all tropical wood species in blocks form. To assist this project, FRIM provides wood samples in small cubic form sized 1 inch by 1 inch approximately. A wood database was built in CAIRO for this project using the wood samples

This master's research focuses on feature selection algorithm in the automatic wood species recognition system. Feature selection algorithm used is Genetic Algorithm. Feature selection algorithm for this system was programmed in such a way that it can be used on any wood databases. Therefore, if there are new wood databases in future, they can still use the same feature selection algorithm.

In the attempt to increase system's performance, the feature selection algorithm must be supported by other good feature extraction algorithm and classifiers. Therefore, the scope of this research is expanded to finding the most compatible feature extraction method and classifiers. GA used in this system is wrapper GA where a classifier was embedded inside GA. Type of classifier can be changed according to the database suitability.

Another part of the research is improving the feature selection algorithm itself. Some improvement is added in the GA operation to increase its performance in term of reducing its operation time to select features. The improvement made was adding a new mutation operation inside GA to create good chromosomes. This results in faster convergence to get optimal solution.

1.6 Thesis Outline

The flow of this thesis is as follows:

- Chapter 1 - Introduction

  This chapter explained about wood recognition process and why there is a need to make the process automatic, how the automatic wood species recognition system was developed and what we did to improve the system. Problem statement and objective of this master's research were included in this chapter.

- Chapter 2 – Literature Review

  This chapter discussed in detail research by other researchers that inspires this research, to decide and choose which algorithm can be used in this master's research.

- Chapter 3 – Methodology

  This chapter explained all methodologies and processes involved in the automatic tropical wood species recognition system.

- Chapter 4 – Experimental Results & Discussions

  This chapter lay out results of experiments that have been done with analysis and discussions.

- Chapter 5 – Conclusions

  This chapter concludes what has been done for this master's research and what is the direction for future research in this project.

REFERENCES

Baas, P., Wheeler, E., et al. (2000). Dicotyledonous wood anatomy and the APG system of angiosperm classification. *Botanical Journal of the Linnean Society*. 134(1-2): 3-17.

Bashar, K.M., Ohnishi, M. (2002). Fusing cortex transform and intensity based features for image texture classification. *Proceedings of 5th Int. Conference on Information Fusion*. 1463–1469.

Bing-Yu Sun, Xiao-Ming Zhang, Jiuyong Li, Xue-Min Mao. (2010). Feature Fusion Using Locally Linear Embedding for Classification. *IEEE Transactions on Neural Networks.* 21(1): 163 – 168.

Bremananth, R., Nithya, B., Saipriya, R. (2009). Wood Species Recognition System. *World Academy of Science, Engineering and Technology.* 52.

Calhoun, V.D., Adali, T. (2009). Feature-Based Fusion of Medical Imaging Data. *IEEE Transactions on Information Technology in Biomedicine*. 13(5): 711-720.

Casson, A., Obidzinski, K. (2002). From New Order to Regional Autonomy: Shifting Dynamics of "Illegal" Logging in Kalimantan, Indonesia. *World Development*. 30(12): 2133-2151.

Chapman, C.A., Chapman, L.J., Jacob, A.L., Rothman, J.M., Omeja, P., Reyna-Hurtado, R., Hartter, J., Lawes, M.J. (2010). Tropical tree community shifts: Implications for wildlife conservation. *Biological Conservation*. 143(2): 366-374.

Choffel, D. (1999). Automation of wood mechanical grading - coupling of vision and microwave devices. *Proceedings of SPIE 1999- The International Society for Optical Engineering*, Boston, MA, USA.

Clausi, D.A., Huang Deng. (2005). Design-based texture feature fusion using Gabor filters and co-occurrence probabilities. *IEEE Transactions on Image Processing*. 14(7): 925 – 936.

Daugman, J.G. (1985). Uncertainty Relations for Resolution in Space, Spatial Frequency, and Orientation Optimized by Two-Dimensional Visual Cortical Filters. *Journal of the Optical Society of America*. 2: 1160-1169.

Dinwoodie, J.M. (1975). Timber, it's Nature and Behaviour. *Journal of Microscopy*, 104(1).

Duda, R., Hart, P., and Stork, D., (2001). Pattern Classification, 2nd ed. *Wiley*. New York.

Ekenel, H.K, Stiefelagen. (2007). Two-class Linear Discriminant Analysis for face recogntion. *IEEE Transactions on Signal Processing and Communications Applications*. 15(11): 1-4.

Faten Hussein, Rabab Ward, Nawwaf Kharma (2001). Genetic Algorithms for Feature Selection and Weighting, A Review and Study. *Sixth International Conference on Document Analysis and Recognition (ICDAR'01), 2001*. 1240.

Fuentealba, C., Simon, C. et al. (2004). Wood products identification by internal characteristics readings. *Proceedings of the IEEE International Conference on Industrial Technology*, Hammamet.

Göberk, B., Dutağacı, H., Ulaş, A., Akarun, L., Sankur, B. (2008). Representation Plurality and Fusion for 3-D Face Recognition. *IEEE Transactions on Systems, Man, And Cybernetics –Part B: Cybernetics*. 38(1).

Grefenstette J, Thompson K, Shannon W, and Steinmeyer B. (2005). Genetic algorithms for feature selection using Mantel correlation scoring. *The Inter Face Classification and Clustering 37th Symposium*. St. Louis, MO.

Guo-Dong Guo, Jain, A.K., Wei-Ying Ma, Hong-Jiang Zhang (2002) Learning similarity measure for natural image retrieval with relevance feedback. *IEEE Transactions on Neural Networks.* 13(4): 811 – 820.

Hadhoud, M.M. (1999). Image contrast enhancement using homomorphic processing and adaptive filters. *Proceedings of the Sixteenth National Radio Science Conference, NRSC '99*.

Haralick, R.M. (1979). Statistical and Structural Approaches to Texture. *Proceedings of the IEEE*. 67: 786-894.

Haralick, R.M., Shanmugam, K. & Dinstein, I., (1973). Textural Features for Image Classification. *IEEE Transactions on Systems, Man, and Cybernetics.* SMC-3(6): 610-621.

Heng-Nian Qi, Feng-Nong Chen, Ling-Fei Ma. (2007). Pore Feature Segmentation Based on Mathematical Morphology. *Industrial Electronics Society, 2007. IECON 2007. 33rd Annual Conference of the IEEE.* 2474 – 2477.

Hoadley, R.B. (1990). Identifying Wood. *Taunton Press.* Newton, Connecticut.

Huan Liu, Lei Yu (2005). Toward integrating feature selection algorithms for classification and clustering. *IEEE Transactions on Knowledge and Data Engineering.* 17(4): 491 – 502.

Ilic, J. (1991). CSIRO Atlas of Hardwoods. *Crawford House Press Pty. Ltd.* Australia.

Ingu, T.; Takagi, H. Accelerating a GA convergence by fitting a single-peak function. *1999 IEEE International Fuzzy Systems Conference Proceedings*. Seoul, Korea.

Iqbal, M. A., Khan, N. K., Mujtaba, H., Baig, A. R. A Novel Function Optimization Approach Using Opposition Based Genetic Algorithm With Gene Excitation. *International Journal of Innovative Computing, Information and Control.* 7(7B).

Johns, A.G. (1996). Bird population persistence in Sabahan logging concessions. *Biological Conservation.* 75(1): 3-10.

Jones, K. O. (2005). Comparison Of Genetic Algorithm And Particle Swarm Optimisation, *International Conference on Computer Systems and Technologies - CompSysTech'2005*. 1-6.

Khairuddin, U., Yusof, R., Khalid, M., Cordova, F (2011). Optimized Feature Selection for Improved Tropical Wood Species Recognition System. *ICIC Express Letters Part B: Applications.* 2(2): 441-446.

Kumar, N., Andreou, A.G. (1996). A Generalization of Linear discriminant Analysis in Maximum Likelihood Framework. *Proceedings of Joint Meeting of American Statistical Association.*

Kurvonen, L., Hallikainen, M.T. (1999). Textural information of multitemporal ERS-1 and JERS-1 SAR images with applications to land and forest type classification in boreal zone. *IEEE Transactions on Geoscience and Remote Sensing.* 37(2): 680 – 689.

Lin, K.L., Chun-Yuan Lin, Chuen-Der Huang, Hsiu-Ming Chang, Chiao-Yun Yang, Chin-Teng Lin, Chuan Yi Tang, Hsu, D.F. (2007). Feature Selection and Combination Criteria for Improving Accuracy in Protein Structure Prediction. *IEEE Transactions on NanoBioscience.* 6(2): 186-196.

Liu, H., Dougherty, E.R., Dy, J.G., Torkkola, K,, Tuv, E., Peng, H., Ding, C., Long, F., Berens, M., Parsons, L., Zhao, Z., Yu, L., Forman, G. (2005). Evolving Feature Selection. *Intelligent Systems, IEEE*. 20(6):64 – 76.

Marinakis, Y., Dounias, G., Jantzen, J. Pap smear diagnosis using a hybrid intelligent scheme focusing on genetic algorithm based feature selection and nearest neighbor classification. *IEEE Computers in Biology and Medicine* 39: 69 – 78.

Marzuki Khalid, Eileen L.Y.L., Rubiyah Yusof, Nadaraj, M. (2008). Design of an Intelligent Wood Species Reocgnition System. *International Journal of Simulation Systems, Science & Technology*. 9(3): 9-19.

Menon, P.K.B., Ani Sulaiman, Choon, L.S. (1993). Structure And Identification Of Malayan Woods. *Malayan Forest Records No 25*, Forest Research Institute Malaysia, Malaysia.

Nithya, R., Santhi, B. (2011). Mammogram Classification Using Maximum Difference Feature Selection Method. *Journal of Theoretical and Applied Information Technology*. 33(2): 197-204.

Petrou, M., Sevilla, G.S. (2006). Dealing With Textures. *John Wiley & Sons Ltd*. West Sussex, England.

Piuri, V., Scotti, F. (2010). Design of an Automatic Wood Types Classification System by Using Fluorescence Spectra. *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews*. 40(3): 358-366.

Raymer, M., Punch, W., Goodman, E., Kuhn, L., and Jain, A. (2000). Dimensionality Reduction Using Genetic Algorithms. *IEEE Transactions on Evolutionary Computations*. 4(2).

Ruhong Li, J. Buongiorno, J.A. Turner, S. Zhu, J. Prestemon (2008). Long-term effects of eliminating illegal logging on the world forest industries, trade, and inventory. *Forest Policy and Economics*. 10(7-8): 480-490.

Sharkawy, R., Ibrahim, K., Salama, M. M. a., & Bartnikas, R. (2011). Particle Swarm Optimization Feature Selection For The Classification Of Conducting Particles In Transformer Oil. *IEEE Transactions on Dielectrics and Electrical Insulation*, *18*(6): 1897-1907.

Sola, J., Sevilla. J. (1997). Importance of input data normalization for the application of neural networks to complex industrial problems. *IEEE Transactions on Nuclear Science*. 3(3): 1464-1468.

Solberg A.H.S., Jain A.K. (1997). Texture fusion and feature selection applied to SAR imagery. *IEEE Transaction on Geosciences and Remote Sensors.* 35(2): 475–479.

Sun, Y., Babbs, C., Delp, E. (2005). A Comparison of Feature Selection Methods for the Detection of Breast Cancers in Mammograms: Adaptive Sequential Floating Search vs. Genetic Algorithm. *Proceedings of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference*. Shanghai, China.

Teknomo, Kardi. (2006). Discriminant Analysis Tutorial. *http://people.revoledu.com/kardi/ tutorial/LDA/*

Thawonmas, R. and Abe, S. (1997). A Novel Approach to Feature Selection Based on Analysis of Class Region. *IEEE Transactions on Systems, Man And Cybernetics-Part B: Cybernetics,* 27(2).

Woods, R.E., Gonzalez, R.C. (1981). Real-time Digital Image Enghancement. *Proceedings of IEEE*, 69(5): 643 – 654.

Wu Jiying, Gaoyun An, Qiuqi Ruan. (2009) Independent Gabor Analysis of Discriminant Features Fusion for Face Recognition. *IEEE Signal Processing Letters*. 16(2): 97 – 100.

Xuejie Qin, Yee-Hong Yang (2007). Aura 3D Textures. *IEEE Transactio on Visualization and Computer Graphics.* 13(2).

Xuejie Qin; Yee-Hong Yang. (2004). Similarity measure and learning with gray level aura matrices (GLAM) for texture image retrieval. *Proceedings of the 2004 IEEE Computer Society Conference on Computer Vision and Pattern Recognition CVPR.* 1: I-326 - I-333.

Yang, W., Li, D., Zhu., L. An Improved Genetic Algorithm for Optimal Feature Subset Selection from Multi-Character Feature Set. *Expert Systems With Applications*. 38: 2733-2740.

YunBing Tang, Cheng Cai, FengFu Zhao (2009). Wood Identification Based on PCA, 2DPCA and (2D)2PCA. *Fifth International Conference on Image and Graphics, 2009 (ICIG '09).* 784-789.

Yusof, R.; Rosli, N.R.; Khalid, M. (2009). Tropical Wood Species Recognition Based on Gabor Filter. 2nd International Congress on Image and Signal Processing, 2009. CISP '09. Tianjin, China. 1-5.

Yusof, R (2010). Project Completion Report (TF0106C213 - Technofund Project)