DEVELOPMENT OF CHILLI LEAF DISEASE IDENTIFICATION USING CONVOLUTIONAL NEURAL NETWORK

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A thesis submitted in
fulfilment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

MARCH 2023

Dedicated to:

Allah s.w.t

For giving me good health during thesis writing.

My Beloved Family

My epitome of strength.

My Beloved Supervisor

For the kind support.

My Beloved Co-Supervisors

For pointing me to the right problem solutions.

My Beloved UTHM Teammates

Friends that have always been together during research years.
Hopefully to achieve what we aspired to.

ACKNOWLEDGEMENT

All the gratefulness to Allah s.w.t for granting me the opportunity to successfully complete the Master of Electrical Engineering thesis, which undoubtedly brought me to new heights of intellectual and emotional enrichment. I would like to express my heartfelt gratitude to my supervisor, Mrs. Zarina Binti Tukiran, and co-supervisors, Dr. Ariffuddin Bin Joret, and Assoc. Prof. Ts. Dr. Mohd Razali Bin Md Tomari for their guidance and care during my time under their supervision. Their endless enthusiasm settings and perseverance are something to be admired and sought after in academics, as well as in life.

This accomplishment is also largely attributed to the unwavering encouragement and support from my family, friends, and the staff at the Faculty of Electrical and Electronics Engineering, Universiti Tun Hussein Onn Malaysia.

ABSTRACT

Over the years, numerous studies have been conducted on the integration of computer vision-based feature descriptors and machine learning classifiers for crop disease identification to help farm owners who need assistance in monitoring crop health. However, these conventional feature descriptors often require manual extraction of various disease features. Improperly extracting disease features that are discriminative from the crop can jeopardise the identification performance of the classifiers. To overcome the limitation of these descriptors, a deep convolutional feature descriptor, namely Convolutional Neural Network (CNN), is implemented in this research for chilli leaf image-based disease identification. Three CNN-based models, namely DenseNet-201, EfficientNet-b0, and NasNet-Mobile, are used in this research. Healthy and diseased chilli leaf images are collected and have their resolution resized prior to the model training. The modified model version of DenseNet-201, EfficientNet-b0, and NasNet-Mobile are also built, with the classification layer of each model (softmax-based) is replaced by a Support Vector Machine (SVM) based layer. The identification performance of DenseNet-201 (softmax-based), EfficientNet-b0 (softmax-based), and NasNet-Mobile (softmax-based) are compared with their modified variants, namely DenseNet-201 (SVM-based), EfficientNet-b0 (SVM-based), and NasNet-Mobile (SVM-based). It is found that the EfficientNet-b0 (SVM-based) model has outperformed the rest of the models with the highest identification performance, where the performance index of accuracy, recall, specificity, precision, and F1-score being 97.33%, 0.97, 0.94, 0.95, and 0.96, respectively. Additionally, a chilli leaf image-based disease identification system in the form of Matlab™ Graphical User Interface (GUI) with captured image input and identification result terminal has been developed in the research to assist farm owners and non-chilli experts in identifying chilli diseases. The EfficientNet-b0 (SVM-based) model is deployed as the core of the developed GUI.

ABSTRAK

Selama bertahun-tahun, pelbagai kajian mengenai integrasi pintu deskriptor berasaskan penglihatan komputer serta mesin pengelas pengenalpastian untuk pengecaman penyakit tanaman telah dilakukan bagi membantu pemilik ladang untuk memantau kesihatan tanaman. Walau bagaimanapun, pintu deskriptor yang konvensional ini selalunya memerlukan pengekstrakan ciri penyakit secara manual daripada tanaman. Pengekstrakan ciri penyakit secara tidak betul daripada tanaman boleh menjejaskan prestasi mesin pengelas pengenalpastian. Untuk mengatasi had deskriptor tersebut, pintu deskriptor berasaskan konvolusi yang mendalam, iaitu Konvolusi Rangkaian Neural (CNN), telah dilaksanakan dalam penyelidikan ini untuk pengenalpastian penyakit berasaskan imej daun cili. Tiga model berasaskan CNN, khususnya, DenseNet-201, EfficientNet-b0 dan NasNet-Mobile, telah digunakan dalam penyelidikan ini. Imej daun cili yang sihat dan berpenyakit telah dikumpulkan dan resolusi imej-imej tersebut diubah saiznya sebelum model-model tersebut dilatih. Versi model ubahsuai DenseNet-201, EfficientNet-b0 dan NasNet-Mobile juga dibina, dengan lapisan pengelasan setiap model (berasaskan softmax) digantikan dengan lapisan pengelasan berasaskan Mesin Sokongan Vektor (SVM). Perbandingan prestasi pengenalpastian telah dibuat antara DenseNet-201 (berasaskan softmax), EfficientNet-b0 (berasaskan softmax) dan NasNet-Mobile (berasaskan softmax). Perbandingan tersebut juga melibatkan versi model ubahsuai, iaitu DenseNet-201 (berasaskan SVM), EfficientNet-b0 (berasaskan SVM), dan NasNet-Mobile (berasaskan SVM). Didapati bahawa prestasi pengenalpastian daripada model EfficientNet-b0 (berasaskan SVM) telah mengatasi model-model yang lain dengan indeks ketepatan, ingatan semula, kekhususan, keperincian dan skor F1 pada 97.33%, 0.97, 0.94, 0.95 dan 0.96. Bagi memudahkan pemilik ladang dan orang bukan pakar hal cili untuk mengenal pasti penyakit cili, sistem pengenalan penyakit berasaskan imej daun cili dalam bentuk Antaramuka Pengguna Grafik (GUI) Matlab™ telah dibangunkan dalam penyelidikan ini. Model EfficientNet-b0 (berasaskan SVM) telah digunakan sebagai teras GUI tersebut.

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LIST OF SYMBOLS AND ABBREVIATIONS

ANN	–	Artificial Neural Network
BPNN	–	Back Propagation Neural Network
CNN	–	Convolutional Neural Network
CMOS	–	Complementary Metal Oxide Semiconductor
CMY	–	Cyan-Magenta-Yellow
CART	–	Classification And Regression Tree
CMV	–	Cucumber Mosaic Virus
CP	–	Convolution Layer
DWT	–	Discrete Wavelet Transform
FP	–	False Positive
FN	–	False Negative
GLCM	–	Gray Level Co-occurrence Matrix
GUI	–	Graphical User Interface
GAP	–	Global Average Pooling
HOG	–	Histograms Oriented Gradient
HSI	–	Hue-Saturation-Intensity
IDM	–	Inverse Difference Moment
KNN	–	K-Nearest Neighbours
LBP	–	Local Binary Patterns
MLP	–	Multilayer Perceptron
MBConv	–	Mobile Inverted Bottleneck Convolution
NAS	–	Neural Search Architecture
PCA	–	Principal Component Analysis
PSNR	–	Peak Signal-to-Noise Ratio
Pepmov	–	Pepper mottle virus
ROI	–	Region Of Interest
RBF	–	Radial Basis Function

RMS	–	Root Mean Squared
RGB	–	Red-Green-Blue
ReLU	–	Rectified Linear Unit
SVM	–	Support Vector Machine
SIFT	–	Scale-Invariant Feature Transform
SURF	–	Speeded Up Robust Feature
SLIC	–	Simple Linear Iterative Clustering
SGDM	–	Stochastic Gradient Descent with Momentum
SQL	–	Structured Query Language
TSWV	–	Tomato Spotted Wilt Virus
TP	–	True Positive
TN	–	True Negative

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CHAPTER 1

INTRODUCTION

This chapter commences with a discussion of the environment for chilli cultivation in Malaysia and the difficulties in ensuring the health of the crop at all times. The difficulties encountered prompt this research to investigate an alternative approach for identifying diseases of the crop in order to monitor its health using a Convolutional Neural Network (CNN) method.

1.1 Background of research

Chilli (Capsicum spp.), an agricultural crop whose fruits are used as a spice in cooking, was introduced in Melaka, Malaysia in the early 1511s [1]. The crop grows upright and entrenched, with a branching green stem and light green to dark green oval leaves. The flower of the crop has five white petals that emerge from the branches with an elongated, and tapered red fruit. The crop belongs to the Solanaceae family; there are about 27 species, but the five best known are C. annuum, C. frutescens, C. pubescens, C. chinense, and C. baccatum [2]. C. annum (varieties CB2, CB3, CB4, CB6, MC11, MC12, and Kulai) is the most popular among locals, with the Kulai variety being widely grown by Malaysian farmers owing to the economic value of its fruits [3]. Nevertheless, chilli production in Malaysia has declined significantly since 2013, as shown in the chart of Figure 1.1. A similar trend is also observed in chilli farming area, as shown in the chart of Figure 1.2. These charts demonstrate that although chilli has significant economic value, export remains a major challenge in both the domestic and international sectors.

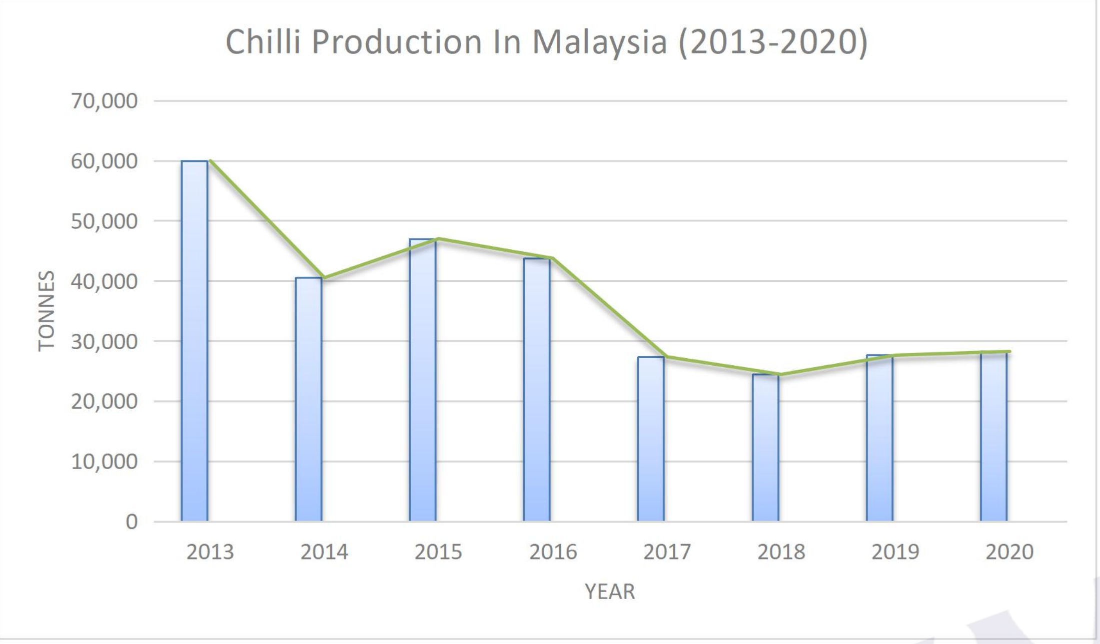


Figure 1.1: Malaysia chilli production from period 2013-2020 [4, 5]

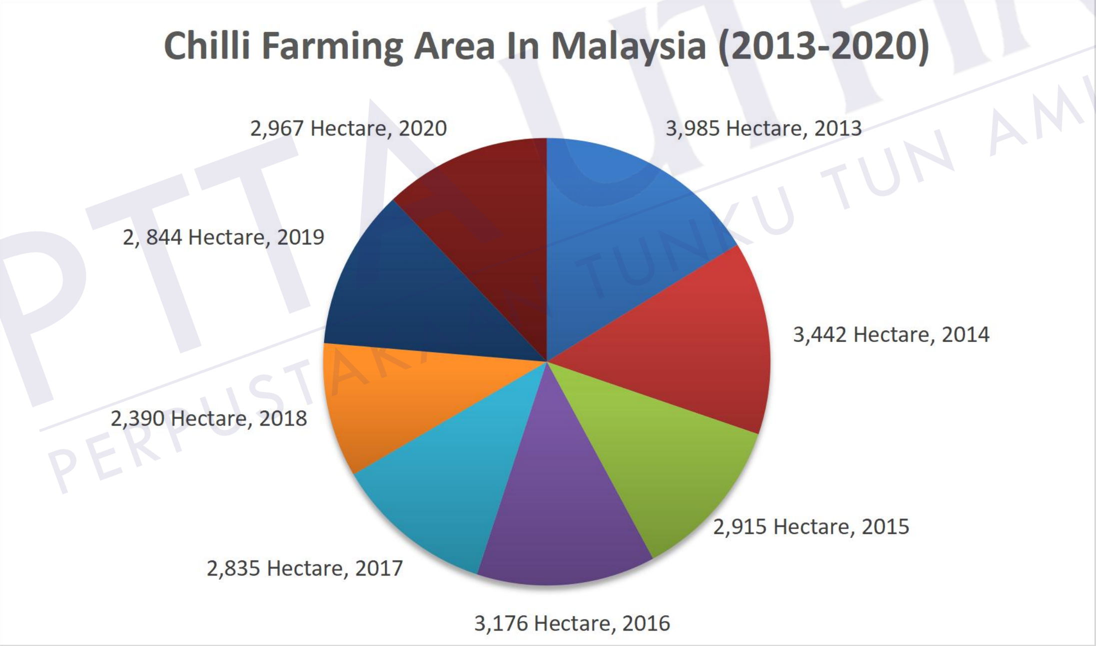


Figure 1.2: Malaysia chilli farming area from period 2013-2020 [4, 5]

With a diverse biodiversity of micro-organisms and high rainfall frequency throughout the year, the agricultural climate in Malaysia results in high air and soil humidity in crop farming areas. Chilli nutrition absorption, like other agricultural crops, is hampered by diseases induced by the resulting climate and pathogen-related infection [6]. These diseases can prohibit significant production of chilli for export [7, 8]. Subsequently, the diseases can be categorised depending on the morphological symptoms that appear on the crop, such as root, stem, flower, fruit, or leaf. However, it is reported that more than 60% of diseases affecting agricultural crops are simply found on the leaf [9-11]. Table 1.1 to Table 1.3 describes the locations of various morphological symptoms of chilli diseases, which are found on the root, fruit, and leaf.

Table 1.1: Morphological symptoms of chilli disease found on the root

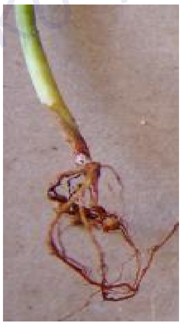
Location	Disease	Symptoms	Sample	Ref.
Root	Root-knot	The formation of swollen spherical regions, also known as root galls, can be observed throughout an infected root system. The pathogen responsible is Meloidogyne incognita.		[12]
	Damping-off	The development of brown and moist lesions on the roots, which results in stunted growth. The pathogens responsible are Pythium spp., Fusarium spp., and Sclerotinia spp.		[13]
	Root Rot	The changes of young crop roots from firm and white to black or brown and mushy are due to the pathogen Rhizoctonia solani.		[14]

Table 1.2: Morphological symptoms of chilli disease found on the fruit

Location	Disease	Symptoms	Sample	Ref.
Fruit	Fruit Rot	Small, black, round lesions primarily occur on the fruits. The pathogens responsible are Colletotrichum truncatum, Colletotrichum gleosporoides, and Colletotrichum acutatum.		[15]
	Bacterial Soft Rot	The formation of water-soaked lesions that quickly spread and cause fruits to degenerate, resulting in a slimy and foul-smelling mess. The pathogen responsible is Erwinia carotovora.		[16]
	Phytophthora Blight	Infected fruit pods start shriveling and decaying, and white mold grows within the pod. Once inside the fruit, the pathogen infects the seeds. The pathogen responsible is Phytophthora capsici.		[17]

Table 1.3: Morphological symptoms of chilli disease found on the leaf

Location	**Disease**	**Symptoms**	**Sample**	**Ref.**
Leaf	Bacterial Leaf Spot	The presence of small, dark brown, round spots is observed. The tissue in the center of the spots becomes lighter and is surrounded by darker borders as the size of the spots increases. The pathogen responsible is Xanthomonas campestris pv. vesicatoria.		[18]
	Powdery Mildew	On the undersides of leaf surfaces, light green spots of growth appear. Over time, the affected regions gather and result in the overall whitening of the leaf. The pathogen responsible is Leveillula taurica.		[19]
	Cucumber Mosaic	Development of necrotic spots, and irregular patterns on the leaf surface. Eventually, the leaf twists and curls. The pathogens responsible are the Cucumber Mosaic Virus and Potato Virus Y.		[20]

By identifying symptoms of chilli diseases, targeted disease controls can be triggered, where disease can be treated, and even the prevention of disease outbreaks. Subsequently, disease prevention measures such as pruning and pesticide deployment schedules, harvest timing, and farm drainage system design can be carried out before further chilli health degradation occurs. These measures have the potential to boost Malaysia chilli export industry in two ways. The first is an increase in chilli yield for exportation or a reduction in yield loss to guarantee domestic food security for spices. The second is an increase in the efficacy of phytosanitary treatments so that less chilli is irradiated when exported. To achieve these goals, this research concentrates on developing a chilli leaf image-based disease identification system using a CNN method. The system is intended to assist farm owners and individuals who are not chilli experts in monitoring chilli health, which can be healthy or diseased depending on the disease symptom.

1.2 Problem statement

Due to the climate characteristics of high ambient humidity and diverse insect biodiversity, the health level of chilli is unpredictable, resulting in varying chilli yield and quality. The inability of farm owners to identify unusual signs of chilli health and take precautionary measures against chilli diseases is hampered by the lack of technology-based inspection equipment and proper disease identification standards set by qualified crop pathologists [9]. In addition, the massive importation of cheap foreign labour with varying levels of work experience to farms makes it difficult for farm owners or labour agents to provide job-related technical training [8], let alone disease identification, which requires decades of experience. Conventionally, the chilli health is determined manually by naked eye inspection or by laboratory testing for detailed analysis [9]. The commonly practised procedure for monitoring chilli health is laborious and time-consuming. At times, the laborious procedure is also prone to error as it is done by humans.

As a result, daily monitoring of chilli health using manual methods is less efficient for farming operations. However, farm owners can benefit from modern practices available for monitoring chilli health, such as the use of computer vision-based feature descriptors. Several studies have been conducted on the integration of computer vision-based feature descriptors and machine learning classifiers to identify diseases from chilli leaf images over the years, such as Gray Level Co-occurrence Matrix (GLCM) [21], Histograms Oriented Gradient (HOG) [22], and Scale-Invariant Feature Transform (SIFT) [23]. Although these conventional feature descriptors have shown promising results, they often rely heavily on the correct selection of manually extracted disease features. Improperly extracting disease features that are discriminative from the crop can jeopardise the identification performance of the classifiers [22].

In this regard, a deep convolutional feature descriptor, specifically the CNN, has made a promising achievement. The CNN can learn and extract the low-level and high-level features necessary for classification, thereby eliminating the need for manual feature extraction [24].

1.3 Aim

This research aims to overcome the limitation of conventional feature descriptors described in Section 1.2 by using a deep convolutional feature descriptor, namely the CNN, to identify diseased chilli leaf. At the end of this research, a chilli leaf image-based disease identification system in the form of Matlab™ Graphical User Interface (GUI) with captured image input and identification result terminal is built in order to assist farm owners and non-chilli experts for disease identification purposes. The CNN with the highest identification performance is selected and deployed as the core of the built GUI.

1.4 Objectives

The objectives of this research are as follows:

i. To identify chilli leaf diseases using three pretrained CNN-based models with their softmax-based layers.

ii. To modify CNN-based models using the SVM-based layers in order to identify chilli leaf diseases.

iii. To compare the performance of pretrained and modified CNN-based models in terms of identification performance.

1.5 Scopes of research

The scopes of the research are:

i. This research uses chilli leaf datasets from Kaggle, a public image dataset website. There are 3000 images of chilli leaf in the datasets, both healthy and diseased. The first 1000 images are in the category of healthy, the next 1000 images are in the category of Bacterial Leaf Spot disease, and the last 1000 images are in the category of Powdery Mildew disease.

ii. DenseNet-201, EfficientNet-b0, and NasNet-Mobile are the three pretrained CNN-based models utilised to identify healthy and diseased chilli leaf, whereas the classification layer of these models (softmax-based) is used for feature classification.

iii. The modification of the CNN-based model is performed at the classification layer of each pretrained CNN-based model by replacing the softmax-based with SVM-based for the feature classification task. The modified CNN-based models are namely DenseNet-201 (SVM-based), EfficientNet-b0 (SVM-based), and NasNet-Mobile (SVM-based).

iv. All CNN-based models are trained using 2100 images, and the remaining 900 images are used to test the models. The output of these models is their identification performance. In order to measure their identification performance, five performance indexes are computed from the confusion matrix generated from a model testing result that are accuracy, recall, specificity, precision as well as F1-score.

v. The model with the highest identification performance is integrated into the development of a GUI-based chilli leaf-image disease identification system.

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APPENDIX A

LIST OF PUBLICATIONS

Journals

1. Aminuddin, N., F., Tukiran, Z., Joret, A., Tomari, R., and Morsin, M. "An Improved Deep Learning Model of Chilli Disease Recognition with Small Dataset," Advanced Computer Science and Applications, 13(7), 2022, doi:10.14569/ijacsa.2022.0130750 **(SCOPUS-indexed)**
2. Aminuddin, N., F., Joret, A., Zulkifli, S., A., Abdul, K., H., Morsin, M., and Tukiran, Z. "Computational Approaches Based On Image Processing for Automated Disease Identification On Chili Leaf Images: A Review," Emerging Advances in Integrated Technology, 3(2), 2023 **(Non-SCOPUS)**

Proceedings

1. Aminuddin, N., F., Tukiran, Z., Joret, A., Roslee, M., N., Yamaguchi, S., and Ahmadon, M., A. "Hungarian-Particle Filtering Based Segmentation for On-Road Visual Vehicle Detection and Tracking," IEEE, 600, 2022, e-ISBN-9781 665419048 **(SCOPUS-indexed)**

APPENDIX B

VITA

The author was born on March 1, 1995, in Kedah, Malaysia. He earned a degree (Hons.) majoring in Electronic Engineering from Universiti Tun Hussein Onn Malaysia in 2020. During his studies, he developed a final year project that earned him a Best Project Award and a People Choice Award from Universiti Teknologi MARA. He also received the highest award for the project, a Platinum Medal Award, from the University of Malaya during the International Summit on Innovation and Design Competition. In total, he received seven Platinum Medals, four Gold Medals, and two Silver Medals for numerous projects he developed during his studies. Due to the achievements, he was honored with the Young Innovator Award by the Institute of Electrical and Electronics Engineering (IEEE) Malaysia. Moreover, he achieved a remarkable feat by securing second place and RM2,000 prize in the Innovate Malaysia Design Challenge (IMDC) team competition for the Matlab^{TM} Technology Track, being the only individual participant competing. Afterwards, he managed to pass the Machine Learning Specialist (ML90.1) exam conducted by the collaboration of Ministry of Higher Education (MoHE) Malaysia and Arcitura Education Inc. with distinction (he received a 96% score with a passing grade of 72% score). During the exam preparation, he also authored a book chapter in a published book titled Image Processing: Issues and Solutions. After graduation, he worked for a short period as a research assistant to an associate professor in the Electronic Department of the Faculty of Electrical and Electronics Engineering, Universiti Tun Hussein Onn Malaysia. He then re-enrolled in the same faculty for a Master degree program on March 15, 2021.