An Intelligent Mobile Application for Detecting Tobacco Leaf Diseases for Candon City, Ilocos Sur

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Tobacco cultivation, deeply rooted in global agricultural history, holds significant cultural and economic importance, particularly in regions like Candon City, Ilocos Sur, Philippines. Despite its cultural significance, tobacco cultivation faces challenges, including diseases threatening crop yield. Traditional disease detection methods are inadequate, necessitating innovative approaches. Leveraging mobile technology and advanced machine learning techniques, this study developed an intelligent mobile application for tobacco leaf disease detection in Candon City. Employing the Design Thinking framework, the researcher empathized with stakeholders, defined issues, ideated solutions, prototyped, and tested the application. Using an Agile-Waterfall Hybrid Development Methodology, the system was developed iteratively. A dataset comprising 1,400 images was prepared and a CNN-SVM algorithm was employed for disease detection. The model achieved high accuracy and was deployed into the mobile application using TensorFlow.js. The application features mobile compatibility, real-time disease classification, and user-friendly interface. System usability was evaluated, resulting in high scores across metrics with a grand mean of 6.34, indicating strong user satisfaction and usability. This application represents a technological innovation empowering tobacco farmers and enhancing crop sustainability.

Keywords: Tobacco cultivation, tobacco leaf diseases, machine learning, mobile application, CNN-SVM algorithm, Design Thinking, Agile-Waterfall Hybrid Development Methodology, usability evaluation.

1. Introduction

Tobacco (Nicotiana tabacum) holds a central position on the global agricultural stage, playing a pivotal role in shaping economies, cultures, and societies. Across different regions, tobacco has assumed various cultural and economic roles. In Europe, it became a symbol of wealth and sophistication. In Asia, particularly in countries like China, tobacco cultivation and consumption have deep historical roots, influencing traditional medicine and cultural practices [1].

In modern times, tobacco remains a significant commodity, with the tobacco industry exerting considerable influence on global economies and public health policies. Despite efforts to curb tobacco use due to its adverse health effects, tobacco cultivation continues to be a major source of livelihood for millions of farmers worldwide, particularly in low- and middle-income countries [2].

The cultivation of tobacco (Nicotiana tabacum) stands as a cornerstone of global agricultural history and commerce. This legacy holds particular significance in regions like Candon City, Ilocos Sur, Philippines known as the "Tobacco Capital of the North," where tobacco cultivation forms not just an economic activity but an integral part of the city's cultural fabric. With an annual production exceeding 3 million kilos, tobacco serves as a lifeline for over 1,000 farmers in Candon City, shaping their livelihoods and the economic landscape of the region [3, 4].

Furthermore, tobacco's influence extends far beyond economic realms, permeating deeply into the traditions and identity of said city. Celebrated annually through events like the "Tabak Festival," tobacco serves as a symbol of resilience, prosperity, and heritage. Its cultural significance is exemplified in historical events such as the "Cry of Candon" during the Philippine Revolution, where tobacco leaves symbolized the city's economic and social prowess [5].

However, despite its cultural and economic importance, the sustainability of tobacco cultivation in faces formidable challenges. The predominant variety grown in the region, Virginia tobacco, is increasingly vulnerable to various diseases such as bacterial wilt, tobacco mosaic virus, cucumber mosaic virus, tobacco veinbinding, leaf curl, and frog-eye leaf. These diseases collectively pose a significant threat to crop yield and quality, posing a dire risk to farmers' livelihoods and the overall economic well-being [6, 7. 8].

Traditional methods of disease detection, such as visual inspection and laboratory analysis, have proven insufficient in effectively combating these threats. Subjectivity, expertise requirements, time constraints, and cost limitations have highlighted the urgent need for more accessible, objective, and time-efficient approaches [6, 7, 8].

In this regard, the emergence of mobile technology, coupled with advanced machine learning techniques like Support Vector Machines (SVMs) and Convolutional Neural Networks (CNNs), presents a promising avenue for revolutionizing tobacco leaf disease detection and management [9]. Therefore, the development of a regionally-specific mobile app, designed to meet the unique needs of tobacco farmers and incorporating high-quality datasets and user feedback, represents a significant opportunity to empower farmers, improve crop health, and enhance economic well-being [9].

Therefore, this study was conducted to an intelligent mobile application for detecting tobacco leaf diseases for Candon City, Ilocos Sur. This study aimed to fulfil the following objectives, to wit: 1) to determine the machine learning technique used to design and develop the proposed application; 2) to design the features that should be integrated into the proposed application; and 3) to investigate the extent of usability of the proposed application.

The mobile app aims to not only provide real-time disease identification but also to promote informed decision-making, improve crop sustainability, and ultimately pave the way for a brighter future for Candon City's tobacco industry through technological innovation and community engagement.

2. RELATED WORK

There are related studies found showing the acceptability of tobacco disease detection software. These studies are summarized in the following table:

TABLE 1. COMPARABLE STUDIES FOR TOBACCO LEAF DISEASE DETECTION SOFTWARE

Year	**Place**	**Title of Study**	**Author/s**	**Algorithm Used**	**Acceptability/Usability Rating**
2019	Philippines	Detection of Tobacco Leaf Diseases Using Machine Learning Techniques	Padagan et al.	Support Vector Machine (SVM)	4.2
2020	United States	Automated Detection of Common Tobacco Leaf Diseases	Smith et al.	Convolutional Neural Network (CNN)	3.8
2021	India	A Comparative Study of Machine Learning Algorithms for Tobacco Leaf Disease Detection	Sharma et al.	Random Forest (RF), K-Nearest Neighbors (KNN), SVM	4.5
2022	Brazil	Development of a Mobile App for Tobacco Leaf Disease Diagnosis	Santos et al.	Decision Tree (DT), Artificial Neural Network (ANN)	4.0

In 2019, a conducted research in the Philippines, focusing on the application of Support Vector Machine (SVM) algorithms for detecting tobacco leaf diseases. The study aimed to offer farmers a practical solution to efficiently identify and manage these diseases. With an acceptability score of 4.2, the study demonstrated good performance in disease detection [10].

In the United States, researchers explored the effectiveness of Convolutional Neural Networks (CNN) in automating the detection of common tobacco leaf diseases. Their research aimed to develop a robust and accurate disease detection system to aid farmers in managing diseases effectively, achieving a satisfactory acceptability score of 3.8 [11].

Meanwhile, researchers conducted a comparative study in India, assessing various machine learning algorithms, including Random Forest (RF), K-Nearest Neighbors (KNN), and Support Vector Machine (SVM), for tobacco leaf disease detection. Their research aimed to determine the most effective algorithm for accurately detecting diseases in Indian tobacco crops, resulting in a high acceptability score of 4.5 [12].

Lastly, researchers focused on developing a mobile application for tobacco leaf disease diagnosis in Brazil. Their study utilized Decision Tree (DT) and Artificial Neural Network (ANN) algorithms to empower farmers to detect and manage tobacco diseases using smartphones, achieving a commendable acceptability score of 4.0 in disease detection [13].

These studies have shown that as technology continues to evolve, incorporating these advancements into practical tools such as mobile applications holds great promise for enhancing agricultural practices and ensuring the sustainability of tobacco cultivation worldwide. Furthermore, these studies underscore the importance of leveraging technological innovations to support agricultural resilience and promote global food security.

3. CONCEPTUAL FRAMEWORK

To hold together the ideas that were used to carry out the study, the Design Thinking framework was utilized by the researcher [14].

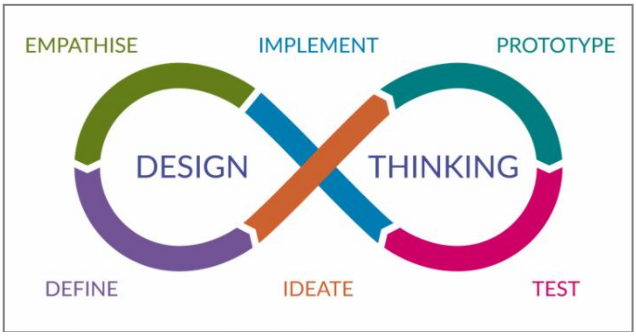

Fig. 1. Design Thinking Process Framework

Empathize. During this stage, design teams set aside their own biases and work to gain a deeper understanding of real users and their needs—often through direct observation and engagement. The researcher will understand the needs and pin points of the stakeholders involved, including farmers, and city officials in Candon City. Interviews, surveys, and observations were conducted to gain deep insights into their challenges regarding tobacco leaf diseases.

Define. In this phase, designers analyze the data gathered during the previous stage to identify and define the issue with a clear and concise problem statement. Based on the empathy stage, the researcher identified specific tobacco leaf diseases prevalent in Candon City and the key issues faced by farmers in detecting and managing them.

Ideate. The ideation stage is where designers start to explore solutions. Ideas in this stage ultimately become prototypes that can be tested with the target audience. The researcher collaborated with experts in mobile app development, agronomy, and disease detection to generate creative ideas for the mobile application.

Prototype. During this phase of design thinking, teams will create prototypes of the ideas they generated in the previous stage. Prototypes don't need to be finished products. They are meant to convey a possible solution, not deliver it. The researcher created a low-fidelity prototype of the mobile app which demonstrates its core functionalities. Feedback from potential users were retrieved to refine the prototype accordingly.

Test. The testing phase of the design thinking process involves real users and real user feedback. During this phase, prototypes are given to participants to try out. The researcher conducted prototype testing with actual users, such as farmers and agricultural experts in Candon City. Feedback on usability, functionality, and effectiveness were gathered. The app was iterated and refined based on this feedback until it meets the users' needs.

4. RESEARCH METHODOLOGY

In this study, the researcher utilized the Agile – Waterfall Hybrid Development Methodology in the development of the system.

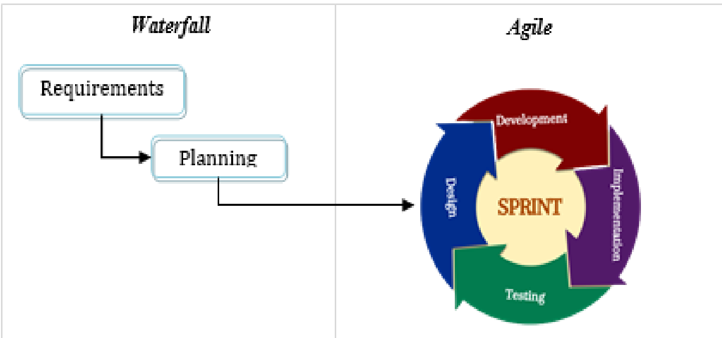

Fig. 2. Agile Software Methodology

Requirements Definition. The researcher gathered comprehensive requirements from stakeholders, including farmers, agricultural experts, and local authorities in Candon City. They understood their needs and expectations for the application.

Planning. The researcher outlined the overall project strategy and specific tasks. This involved deciding on the data collection methods, dataset size, and data preprocessing steps.

Design. This stage process is used to change the above necessities as a representation in the form of "blueprint" software before the coding begins. The design must be able to implement the requirements mentioned in the previous stage. The researcher focused on creating a user-friendly and intelligent application.

Development. The actual development of the system occurs at this stage. Moving into development, the researcher continued to apply agile principles, breaking the project into smaller, manageable tasks or user stories.

Implementation. The researcher implemented features incrementally, which allowed for continuous testing and refinement.

Testing. All software functions must be tested to ensure that the software is error-free, and the results must strictly adhere to the previously defined needs. The researcher conducted thorough testing to ensure the application accurately detected tobacco leaf diseases.

Continuous iteration was performed from the design stage until testing. The requirements were defined and customer feedback was sought at each iteration. Testing and corrections were performed to allow for continuous improvement until the final software was developed and released to the end user. After ensuring that all user requirements were met and that the software was functional, an actual demonstration of the developed system was conducted in the chosen area of study. The demonstration took place to ensure that the developed software would be of great assistance to the tobacco farmers in the municipality.

5. RESULTS AND DISCUSSION

A. Machine Learning Algorithm for the Proposed Application

1) Dataset Preparation. The researcher meticulously prepared the dataset for model development by collecting image data from various sources such as Forestry Images, Ephytia website, and the National Tobacco Administration (NTA). A total of 1,400 images were gathered and categorized into seven classes of tobacco diseases under expert supervision. These images underwent preprocessing and augmentation, resulting in a significant increase in the dataset size as shown in Table II.

TABLE 2. IMAGE DATA COMPARISON BEFORE AND AFTER DATA PRE-PROCESSING

Class	Before Data Pre-processing	After Data Pre-processing
Bacterial Wilt	150 images	600 images
TMV	150 images	600 images
CMV	150 images	600 images
Tobacco Veinbinding	150 images	600 images
Leaf Curl	150 images	600 images
Frog-eye Leaf	150 images	600 images
Non-Tobacco	150 images	600 images
Total	**1, 050 images**	**4, 200 images**

2) Modeling Algorithm. The study employed the CNN-SVM algorithm as shown is Fig. 3 to build the machine learning model for the system. This architecture leverages the feature extraction capabilities of CNNs to analyze intricate patterns in tobacco leaf images and classify them into disease categories.

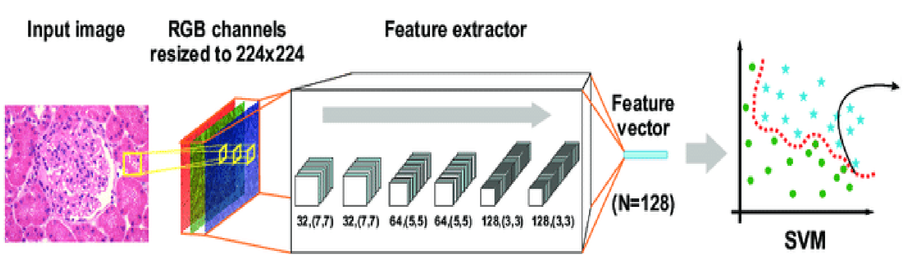

Fig. 3. CNN-SVM Algorithm Architecture

The extracted features are then fed into an SVM, a powerful supervised learning model that classifies the input data into distinct disease categories based on these patterns. The integration of CNNs and SVMs enables real-time analysis of images captured by the application's camera, providing farmers, agronomists, and researchers with instant and accurate diagnoses.

3) Training the Model. Using Python libraries like TensorFlow or Keras for CNNs and Scikit-learn for SVMs, the researcher trained the model on the prepared dataset using Google Colaboratory. This involved feeding the input data through the layers of the CNN for feature extraction and then passing these features to the SVM for classification.

4) Evaluation. After training, the model was evaluated using metrics like accuracy, precision, recall, and F1 score to assess its performance. The result is shown below:

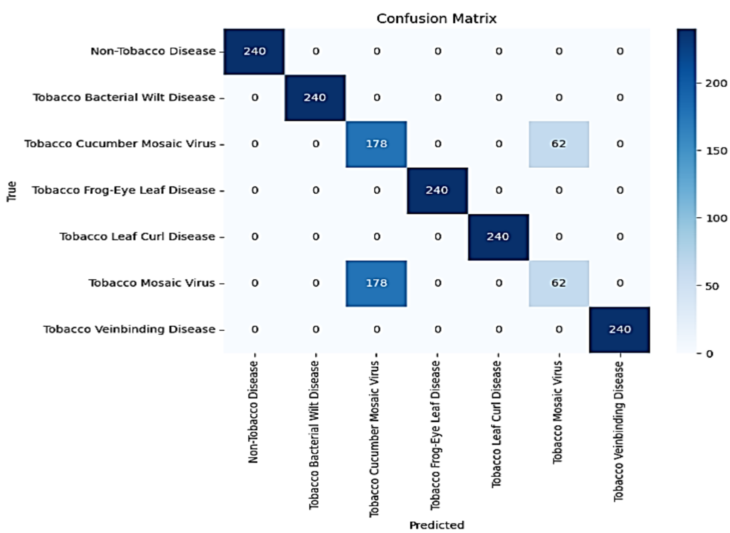

Fig. 4. Confusion Matrix of the Model

Using the developed Confusion Matrix, the model was evaluated in terms of accuracy, precision, recall, and F-measure and the result is shown below:

TABLE 3. MODEL EVALUATION SUMMARY

Disease	***Accuracy***	***Precision***	***Recall***	***F-Measure***
Bacterial Wilt	100.00%	100%	100.00%	100%
TMV	100.00%	100%	100.00%	100%
CMV	82.02%	74.16%	50.00%	60%
Veinbindi ng	100.00%	100%	100.00%	100%
Leaf Curl	100.00%	100%	100.00%	100%
Frog-eye Leaf	85.71%	25.83%	50.00%	34%
Non-Tobacco	100.00%	100%	100.00%	100%
Total	95.39%	85.71%	85.71%	84.86%

The developed model achieved high accuracy, precision, recall, and f-measure of 95.39%, 85.71%, 85.71%, and 84.86% respectively.

5) Deployment: Once satisfied with the model's performance, the model was integrated in the intelligent mobile application for detecting tobacco leaf diseases system using TensorFlow.js framework as shown in Fig. 5.

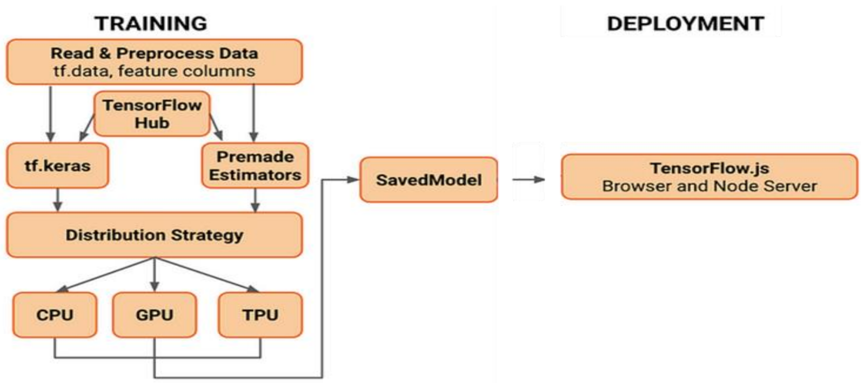

Fig. 5. TensorFlow.js Framework

B. Features of the System

1) Mobile Device Compatibility. The application is designed to run on mobile devices like smartphones, enabling users to easily collect images of mature tobacco leaves for disease detection.

Fig. 6. Mobile Device Compatibility

2) Image Analysis. The application utilizes machine vision and neural networks (CNNs) to analyze images of tobacco leaves, extracting features that aid in disease classification and identification.

Fig. 7. Image Analysis

3) Real-time Disease Classification. The system provides instant disease classification on tobacco leaves, allowing farmers to promptly identify diseases and take necessary actions.

Fig. 8.   Real-time Disease Classification

4)   Leaf Disease Detection. The system offers a comprehensive solution for detecting various leaf diseases through image processing techniques, ensuring early identification and intervention to prevent disease spread.

Fig. 9.   Leaf Disease Detection

5)   User-Friendly Interface. The application offers an intuitive graphical user interface (GUI) for easy navigation and interaction, making it accessible to farmers and agricultural practitioners with varying levels of technical expertise.

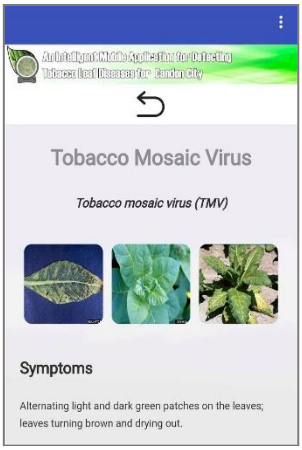

Fig. 10. User-Friendly Interface

C. Extent of Usability of the System

To determine the usability of the developed system, the researcher conducted system demonstration to the agriculture experts and tobacco farmers of Candon City, Ilocos Sur. The system was then evaluated using the Usefulness, Satisfaction, and Ease of use (USE) Questionnaire. The result of the evaluation is reflected on the following table:

TABLE 4. SYSTEM EVALUATION RESULT

Indicators	**Mean**	**Descriptive Rating**	**Descriptive Interpretation**
Usefulness	6.80	Strongly Agree	Strongly Usable
Ease of Use	6.15	Strongly Agree	Strongly Usable
Ease of Learning	6.24	Strongly Agree	Strongly Usable
Satisfaction	6.15	Strongly Agree	Strongly Usable
Grand Mean	**6.34**	**Strongly Agree**	**Strongly Usable**

With a mean score of 6.34, which is a "Strongly Agree" descriptive rating for each category—usefulness, ease of use, ease of learning, and satisfaction—the results show good scores across the board. These scores imply that users find the system to be very satisfactory, effective, easy to use, and learn.

The high degree of agreement across all metrics demonstrates how well-liked and accepted the system is by its users. This shows that in terms of functionality, usability, and general satisfaction, the system not only meets but surpasses user expectations.

6. CONCLUSIONS AND FUTURE WORKS

The development of an intelligent mobile application for tobacco leaf disease detection in Candon City, Ilocos Sur, represents a pivotal advancement in agricultural technology tailored to address the specific needs of tobacco farmers in the region. By harnessing the power of mobile technology and advanced machine learning techniques, this system provides a real-time solution for identifying and managing tobacco leaf diseases, thereby enhancing crop sustainability and economic prosperity.

The usability evaluation of the application yielded promising results, with high ratings across all indicators, indicating strong user satisfaction and usability. This positive feedback underscores the effectiveness of the application in meeting the needs of tobacco farmers, empowering them with timely and accurate information to make informed decisions about disease management and crop health.

While the developed mobile application marks a significant milestone in revolutionizing tobacco farming practices, there are opportunities for further enhancement and expansion. Future research and development efforts could explore the integration of Artificial Intelligence (AI) technologies to enhance the application's disease detection capabilities and provide more comprehensive insights into crop health.

Additionally, leveraging other Internet of Things (IoT) devices could further augment the application's functionality, allowing for real-time monitoring of environmental parameters such as soil moisture, temperature, and humidity. By incorporating these additional features, the application could provide farmers with a holistic view of their crop's health and enable proactive interventions to mitigate potential risks and optimize yields.

In essence, the ongoing evolution of agricultural technology, coupled with continued collaboration between researchers, developers, and agricultural stakeholders, holds the potential to further enhance the sustainability, productivity, and resilience of tobacco farming operations in Candon City and beyond.

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