Coffee rust detection and recommendations module through deep learning algorithms.

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***Abstract*— In recent years, coffee has faced a global increase in plagues and diseases, impacting the quality and profitability of its benefits. One of the most devastating and common diseases is coffee rust, which has caused a significant decrease in coffee production at the national and state levels by causing the falling of mature and young leaves, reducing production. In this work, we present a mobile application development using a deep learning algorithm model to identify and predict the level of coffee rust infection, providing treatment and prevention recommendations for coffee farmers. The model classified with an accuracy of 58% of rust diseased leaves in a dataset of diseased and healthy leaves.**

Keywords—Rust, coffee, plagues, deep learning

I. INTRODUCTION

Rust is a disease that affects coffee crops and can cause a significant reduction in coffee bean production. It became a topic of great interest in the coffee industry worldwide after it devastated large coffee plantations in Ceylon, an Asian island now known as Sri Lanka and also the main coffee producer in 1869. Shortly after, the disease spread to coffee plantations in Indonesia and the Philippines, wreaking havoc in those regions. From 1970 onwards, coffee leaf disease began to invade the coffee-growing regions of North and South America, which led all coffee-growing countries to implement programs for its control [1].

Approximately 95% of coffee production in Mexico is obtained from the Arabica species, vulnerable to rust, which has generated heavy crop losses since it arrived. At the national level, it has caused a reduction in production of more than 50% between 2012 and 2016 (from 4.3 million to only 2.2 million bags), corresponding to the lowest levels in the last 50 years [2].

During the 2021-2022 harvest, approximately 50% of the coffee plantations in Veracruz were damaged by the plague because they suffered a worrying mutation. The problem has been particularly evident in areas near Xalapa, such as Cosautlán de Carvajal, Naolinco, and Tepetlán [3]. Although there are currently around 90 thousand hectares of coffee in the state, it is estimated that 45 thousand of them have been affected by the plague/fungus. According to the Regional Coffee Council of Coatepec, the varieties that used to be resistant to the plague are also being affected [4].

Currently, detection requires visual inspection of the plant leaves, which can be a lengthy process and is not very precise to know the plant's infection level. Therefore, early identification and timely recommendations applying deep learning are crucial to prevent the spread of the disease and minimize its impact on coffee growers.

II. RELATED WORD

A literature review was performed to contextualize and support the research on the proposal. Next, several papers were reviewed, as follows:

Plantix [4] is an application for mobile phones with an Android operating system, which allows accurate detection of plagues and diseases in crops. The application detects more than 400 plant damages through a photo. Plantix shows the best time for weeding, spraying, and harvesting and calculates nutrient requirements according to the plot size.

"Enfermedades de las plantas" [5] is an application for mobile phones with an IOS operating system, which, thanks to a machine learning model, allows the detection of plant diseases and plagues with photos. This application gives access to an encyclopedia that shows preventive and curative measures based on ecological treatment methods, indicating the substances and, in this way, the specific product can be found in the corresponding country.

Pl@ntNet [6] allows identifying plants through a photo or image in the phone's gallery. Once the photo is uploaded, the application asks to indicate the part of the plant that has been captured. Then, it displays a series of images that resemble the plant in the image that has been uploaded, allowing to see the details of each species, the other parts of the plant, or access to information sources and areas in which it has been located.

Blossom [7] is a free application for mobile phones with an IOS operating system, which, thanks to a machine learning model, we can know detailed information about the care they require in terms of watering, propagation, pruning, fertilization, light needs, temperature, and disease detection through a photograph. Blossom identifies more than 10,000 plants, flowers, succulents, and trees with just one picture, and through the Multi Snap mode, you can review images of the same plant to make the identification more accurate.

Picture this [8] is a free application for IOS devices that offers plant identification by uploading a photo of the plant; thanks to its artificial intelligence, it is able to give accurate and instant plant identification results.

Automated Epidemiological Surveillance Systems (EVS) [9] use digital technology for regional plague prevention and management in coffee. These systems have a holistic-systemic approach and focus on crop health. Unlike regulatory surveillance, a holistic-systemic web-based EVS offers descriptive and risk forecasting capabilities, including early warnings based on spatial and temporal analysis.

Coffee Cloud [10], an App for Android and iPhone used by 1,800 farmers, records data on varieties, soil, fertilization, and rust control. Basic and Advanced Diagnostics provide recommendations based on local data.

Deep learning in coffee leaves [11] is an Android application identifying biotic stresses in coffee leaf images. It uses convolutional neural networks to segment and classify leaf lesions caused by plagues and pathogens. The accuracy of severity estimation is greater than 97%.

SIMROCA [12] is an application developed by the Phytosanitary Alert System of the State of Sonora (SIAFESON) to facilitate data capture in the Coffee Rust Phytosanitary Alert System. It is a geographic information system used in several Latin American countries that monitors and evaluates the risk of agricultural crops in real-time. Based on data from satellites, weather stations, and agricultural databases, it helps farmers and decision-makers identify areas vulnerable to extreme conditions, diseases, and plagues, allowing better planning and management of crops and reducing risks associated with agriculture.

Table 1 shows a comparative analysis of the most important similarities and differences.

TABLE I. COMPARATIVE ANALYSIS OF RESEARCH RELATED TO THE DETECTION AND CONTROL OF COFFEE RUST DISEASE IN THE COFFEE PLANT.

Work research	***Problem***	***Contribution***	***Technology***
Plantix, 2018	Plagues and disease detection in vegetables.	Agricultural monitoring and recommendations.	Image processing, machine learning, and Android operating systems.
"Enfermedades de las plantas", 2019	Detection of diseases and plagues in vegetables	Access to treatment encyclopedia	Machine learning and iOS operating systems
Pl@ntNet, 2016	Vegetable plant identification	Information access and localization	Image recognition and mobile applications
Blossom, 2018	Plant care and disease detection	Detailed information and identification	Machine learning and mobile applications
PictureThis	Plant identification.	Accurate results with IA	Artificial intelligence and mobile applications
SVE, 2019	Prevention and management of plagues	Epidemiological surveillance	Web, IoT, Linux/Apache, Arduino, Raspberry Pi
Coffee Cloud,2016	Rust monitoring and diagnosis. Segmentation and classification of foliar lesions.	Prediction and classification model. Basic and advanced diagnosis.	Web, IoT, Linux/Apache, Arduino, Raspberry Pi
SIMROCA	Risk monitoring and evaluation.	Agricultural risk management.	GIS, Satellites, Meteorological Stations, BD
Deep learning in coffee leaves	Identification of biotic stress on coffee leaves	Use of CNN for segmenting and classifying foliar lesions caused by plagues and pathogens.	Convolutional Neural Networks, Machine Learning, Android, Image Processing, Classification Algorithms.

According to the table above, several solutions related to crop plague and disease monitoring and tools for plant identification and care are presented. These solutions address different issues in the agricultural sector and have significantly contributed by using various technologies to achieve their specific objectives.

Doctor Café is a proposed technological solution that provides great value to the user by identifying the stage of rust infection in coffee plants. Through Deep Learning, the application performs early diagnoses. It provides preventive recommendations based on analysis of historical data and relevant environmental conditions, suggesting appropriate recommendations to minimize the spread of the disease and preserve the crop's health. Its ability to forecast the spread of the plague in different periods allows farmers to make informed decisions and protect their nearby hectares, contributing to the sustainability of the crop.

III. ARCHITECTURE DESIGN

A. Description of the architecture

Doctor Café's software architecture is composed of a series of interrelated layers that facilitate the diagnosis and prevention of rust infection in coffee plants:

- Presentation Layer: This layer provides the interface with the end user and comprises two main components: Web Client and Mobile Client. The Web Client offers a landing page and an administrative panel to visualize registered information about fincas, coffee trees, and leaves. The Mobile Client, on the other hand, allows the registration of new data and the uploading or capturing images of coffee leaves for subsequent analysis.
- Module Layer: contains the business logic and is divided into three components: Results, Register, and Image Recognition. The Results component is responsible for providing information on the status of the registrations made by the Web Client or Mobile Client, indicating whether they have been successfully stored or if there have been any problems. The Register component provides a form that allows Web Client or Mobile Client users to enter their data quickly, and the Image Recognition component receives the images of coffee leaves sent by the Mobile Client and processes them to extract relevant information about their status.
- Service Layer: focuses on offering web services and comprises three main components: API General Information, Image Analysis API, and Model. The

API General Information component communicates with the DB General Information component of the Storage layer to send and receive registered information related to fincas, coffee trees, and coffee leaves. The Image Analysis API component receives the coffee leaf images from the Image Recognition component and transmits them to the Model component for analysis. The Model component uses artificial intelligence and deep learning techniques to analyze the images. It returns the results to the Image Analysis API, which sends them to the General Information API component.

- Storage Layer: provides data and image storage and comprises two essential components: DB General Information and Image Server. The DB General Information component stores the information recorded on fincas, coffee trees, and coffee leaves and shares it with the API General Information component. The Image Server component stores the images of coffee leaves sent by the Image Analysis API component for later access.
- Infrastructure layer: Provides external services and consists of a single component: API Maps. This component communicates with the Web Client or the Mobile Client to display geographical maps representing the fincas that are registered, thus enriching the user experience.

The synergistic interaction of these components ensures accurate and effective monitoring of coffee rust in coffee crops, providing users with a valuable tool for making decisions based on preserving and protecting their plantations.

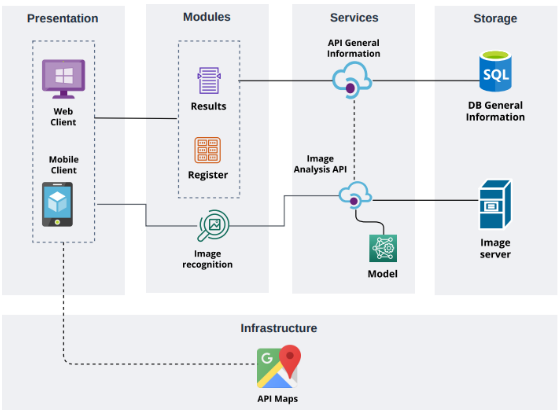

Fig. 1. The architecture of the proposed system.

The login and registration process are implemented through the authentication module. Users must provide their credentials to access their account when logging into the application. The registration module receives the user's data, validates it, and creates an associated account (Figure 2). Once authenticated, users can access all the application's functionalities.

Fig. 2. Logging in.

The results visualization module collects the data of the previously analyzed plants and presents a summary of them in a friendly and easy-to-understand interface (Figure 3). By selecting a specific plant, the application displays a section with more detailed information about the analysis results, including the presence of rust disease-related pigmentation and the percentage of disease progress on the plant.

The module for adding a new coffee plant has been developed for data input (Figure 4). Users can add new coffee plants to be analyzed with the automatic detection algorithm. This module collects the information the user provides and stores it in the database, preparing it to be processed by the automatic detection algorithm.

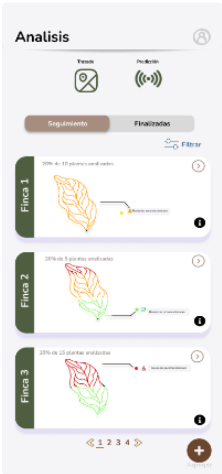

Fig. 3. Results visualization module.

Fig. 4. Module to add a new coffee plant.

The fundamental part of the application is the deep learning module. When the user loads an image, preferably of a coffee plant leaf, to analyze, the algorithm processes the image for the presence of characteristic rust pigmentation on the plant and calculates the percentage of disease progress based on the patterns detected in the image. This algorithm has been designed to be efficient and accurate, allowing the detection and control of rust on coffee plants to be carried out promptly and effectively. The automated analysis process reduces human intervention and speeds up obtaining results, which benefits farmers and coffee experts by providing them with a tool for managing this disease in their crops.

Another contribution is using coordinates to delimit the coffee farm area on Google Maps, which is essential to accurately and visually representing the coffee plantation location (Figure 5). This facilitates planning, management, spatial analysis, and communication with other stakeholders, contributing to better administration and use of the land in coffee production.

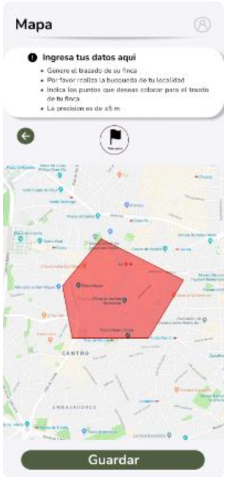

Fig. 5. Module to delimit the area of the coffee plantation in Google Maps.

IV. CASE STUDY

A case study, "Evaluation of Rust Infection in Robusta Coffee Leaves at 'El Cerrito' finca, Ixhuatlán del Café, Veracruz" was conducted to validate the proposed model.

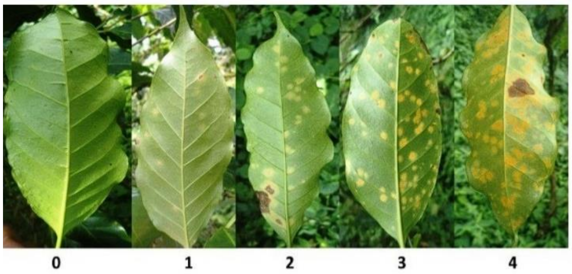

Fig. 6. Phases of rust disease in the coffee plant.

For this purpose, 500 Robusta coffee leaves from different plants on the plantation were collected. Each leaf was photographed in resolution (256 px x 256 px, 720 p) to capture the details of the lesions caused by rust. With these images, a dataset was built to train a deep-learning model to classify and determine the percentage of rust infection on each leaf. The dataset was divided into two categories, each with 250 diseased and healthy photos. A neural network model with three layers and 20 epochs was built using TensorFlow/Keras, performing 35-unit tests and achieving a 58% classification accuracy of diseased and healthy leaves. (Figure 7).

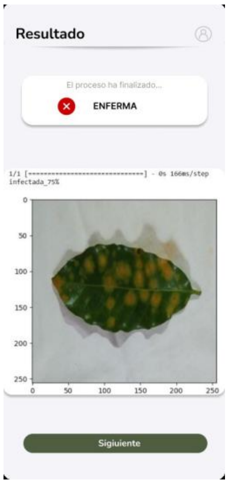

Fig. 7. Result of diseased leaf.

Fig. 8. Healthy leaf result.

The objective was to employ Deep Learning to detect coffee leaf rust accurately. The results yielded information about the degree of leaf disease, allowing producers to make timely decisions to protect their crops and optimize coffee production.

Implementing mobile technology and machine learning in agriculture will help producers apply innovation in the coffee sector by providing them with technological tools to increase the quality of their coffee crops.

V. CONCLUSIONS AND FUTURE WORK

Implementing a neural network model built in TensorFlow/Keras made it possible to successfully evaluate the percentage of rust infection in Robusta coffee leaves in the "El Cerrito" plantations. The accuracy of 58% indicates that the model was adequate to identify and classify the presence of the disease in the analyzed leaves. This approach shows the potential of artificial intelligence to improve the early detection of rust in coffee crops, which will help farmers take preventive measures and mitigate the adverse effects of the disease on coffee production.

The Doctor Café mobile app allowed users to capture images of infected leaves and obtain an early diagnosis of the infection. The application provided treatment and prevention recommendations, which are crucial to minimizing the spread of the disease and maintaining the health of the plantations.

Future work will include improving the training of the recognition model and predictive analysis through Deep Learning to increase the accuracy in the recognition and classification of different coffee varieties. Similarly, incorporating other Deep Learning algorithms will be performed to evaluate the best prediction and classification of rust in coffee plantations.

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