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Proof of Concept Design for Identification of Late Blight on Potato Leaves Using a UAV

Romi Vianne Sullca Bendezu
Ricardo Jose Herrera Baldeon
Deyby Maycol Huamanchahua Canchanya

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Autores:
1. Romi Vianne Sullca Bendezu – EAP. Ingeniería Mecatrónica
2. Ricardo Jose Herrera Baldeon – EAP. Ingeniería Mecatrónica
3. Deyby Maycol Huamanchahua Canchanya – EAP. Ingeniería Mecatrónica

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Proof of Concept Design for Identification of Late Blight on Potato Leaves Using a UAV

Romi Sullca-Bendezu
Dept. of Mechatronic Engineering
Universidad Continental
Huancayo, Perú
72253631@continental.edu.pe

Ricardo Herrera-Baldeon
Dept. of Mechatronic Engineering
Universidad Continental
Huancayo, Perú
75162530@continental.edu.pe

Deyby Huamanchahua
Dept. of Mechatronic Engineering
Universidad Continental
Huancayo, Perú
dhuamanchahua@continental.edu.pe

***Abstract*—Potato is the third most consumed food fruit worldwide by humans and on many occasions at planting time it is affected by numerous fungal species that generate various diseases in potato leaves and tubers, causing great economic losses and obtaining a poor crop production. The objective of this study was to design a proof of concept for the early identification of late blight disease in potato leaves using an unmanned aerial vehicle (UAV), under the terms of technical and economic evaluation of the solution and the concepts of using an embedded system. The late blight identification processes were exposed to the technical and economic evaluation of the solution from three proposed solutions, solution S1, solution S2 and solution S3. The three provided solutions were compared, and the following results were obtained, the technical values Xi obtained the results of 0.86, 0.68 and 0.75 according to the order number of solutions one, two and three and the economic evaluation results obtained the economic values Yi of 0.88, 0.79 and 0.75. The optimal solution for the design of the proof of concept for the identification of late blight on potato leaves is solution S1, and from it the design of the control flow diagram and the schematic communication diagram were developed.**

Keywords—late blight, infection traits, optimal solution, UAV, potato, image processing

I. Introduction

In Peru, late blight and early blight are one of the most worrying diseases for potato growers, causing economic losses to growers nationwide [1]. The appearance of these diseases on potato leaves are pale green spots and dark circular spots [2]. Therefore, the desire to reduce economic losses through a system requires the application of a method to identify diseases on plant leaves in an automated way [3].

Normally, there are monitoring techniques that consist of consecutive checking of the distribution of diseases on potato leaves and require a great effort for their identification. However, from the use of Convolutional Neural Network (CNN), the identification of diseases in potato crop plants would be more accurate and efficient [4, 5]. Similarly, for the identification, characterization, and classification of late blight in plants; it was determined that the use of image segmentation in the Convolutional Neural Network VGG16 has a higher performance and accuracy in its identification purpose [6].

Among the similarities with this article, it is presented that crop leaf disease identification systems have been developed from the use and application of Convolutional Neural Network [7], with the aim of accurately detecting the disease in crop plants in real time. Also, the application of image segmentation using graph cut method for the process of extracting object features from image color and foreground mask textures of potato leaf disease images reduce the consecutive tracking of plants [3]. In addition, the provision of a convolutional neural network classification model for extracted character modeling [5], and the use of an unmanned aerial vehicle for potato late blight tracking and mapping [11]. In addition, this article has the importance of seeking the optimal solution for the upcoming implementation of the design of a late blight identification system on potato leaves for growers.

One of the differences with this article is mentioned in Krishnaswamy and Purushothaman [6] which points out that the VGG16 convolutional neural network classification model used the eighth convolutional layer for feature extraction. Also, Yen-Ju Wu et al [8] proposed a method to reduce the computation time of image features, they first extract the image features and then extract the region of interest (ROI) taking into account the quality of the original image, this technique incorporates color transformation, preprocessing, extraction and classification. On the other hand, many authors have chosen to employ an artificial neural network (ANN) to predict tomato late blight [9]. Similarly, they apply deep neural network and color images for the detection of late blight in wheat crop [10]. On the other hand, this work has the difference of focusing on the evaluation, the best solution to create an effective recognition system for the identification of late blight in potatoes with the use of a UAV and CNN.

This study focuses on an evaluation method to detect late blight on potato leaves using a UAV and the use of an embedded system for its disease identification and classification process. This work applies the triple diamond methodology and uses the applicative research method. It also shows a flowchart for the image segmentation and uses applicative type research and classification process from the VGG16 architecture. The following paper evaluates the solutions for improving fungal detection in potato crops and shows the optimal solution from the use of technical and economic evaluation and the respective evaluation diagram. The communication diagram of the proof-of-concept design for late blight detection in potato leaves is also detailed and conclusions are mentioned in the final part.

II. Method

A. Type of Research

Applied research focuses on transforming theoretical knowledge into practical knowledge, such as concepts and prototypes [12]. One of the advantages of applied research is that it positively impacts the quality of people's lives [12]. This article uses applied research to develop a proof of concept by exposing an integrated system for late blight detection in potato leaves.

B. Research Design

The triple diamond design (Fig. 1) is a methodology developed to make progress clearer, each stage of the three diamonds has an outcome, which provides a better approach to research [13]. Three fundamental stages are distinguished in this methodology:

- Diamond 1: Research, which corresponds to the inquiry to form an idea of the problem, arriving at the result of the first diamond in the form of a hypothesis.
- Diamond 2: Proof of concept, which allows proposing prototypes or presenting a proof of concept good enough to demonstrate its potential value. In this phase, it is essential to develop at least two designs: electronic design, algorithm design or mechanical design.
- Diamond 3: Build and test, which allows the construction of the final prototype that materializes the proof of concept. The result of this third diamond is the final version of the prototype and the data collected from the quantitative and qualitative tests.

The triple diamond methodology was preferred because of its structured stages and specific results at the end of each diamond, thus providing a progressive control of the research.

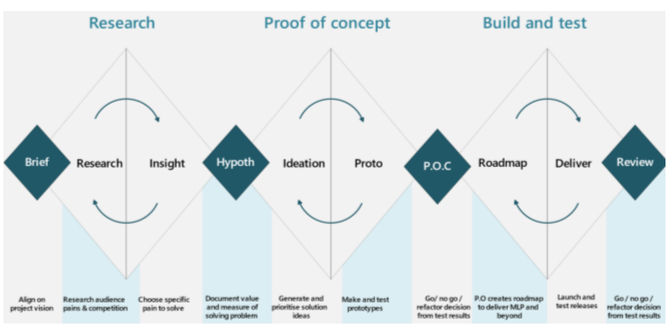

Fig. 1. Structure of the triple diamond methodology [13].

C. Objectives

1) General objetive:

Identifying Late Blight disease in potato leaves using an algorithm coupled to a UAV.

2) Specific objectives:

- Identify leaf characteristics for late blight detection in potato crops.
- Develop a technical and economic evaluation of the VDI 2225 standard.
- Develop a late blight detection algorithm flowchart, applying ANSI standards.
- Develop a schematic diagram of the embedded system.

III. Analysis

A. Infection traits

Phytophthora Infestans is a parasite that causes potato late blight. It is especially present on leaves, presenting a great variety of lesions in its appearance and depending on the environmental condition in which it is found. *Phytophthora Infestans* causes the accumulation of phytoalexins and the hypersensitivity response, which evidences small irregular, dark green or brown spots at the sites of infection due to cell death [14, 15]. Figure 2 shows potato leaves without the disease and potato leaves infected by late blight.

Fig. 2. Images of the potato leaf [16].

B. Detection of Late Blight

1) Image collection

The image collection of the potato leaves is captured through the camera attached to a UAV in RGB (red, green and blue) form. The input images must be resized as the VGG16 architecture design expects a 224 x 224 pixel RGB image [17].

2) Image preprocessing

Enhancement and filtering techniques are used. The guided filter behaves as a smoothing operator that preserves edges and reduces image noise while preserving leaf features and textures [18]. The smoothing filter increases the contrast of the image [19]. And the grayscale image intensity equalization to perform subsequent higher level segmentation operations [20].

3) Image segmentation

The combination of an algorithm between boundary detection and point detection is the method for image segmentation [21]. The RGB image input is transformed into the HSI color saturation intensity model to decouple the image brightness from its color composition, saturation, and intensity [19]. The algorithm helps to locate the infected part of potato leaves by late blight.

4) Character extraction

The feature extraction method is the CCM system that uses color and texture extraction from the image to obtain the unique features displayed by the image [22].

5) Image classification using CNN (Convolutional Neural Network).

CNN requires three procedures: network architecture reconstruction, network training and learning interference [23]. In this aspect, the VGG16 architecture of convolutional neural network is used for image classification. The VGG16 convolutional network diversifies into large varieties of the data set [24]. The CNN (Fig. 3) fundamentally aims to provide a comprehensive learning model for applications such as feature extraction, recognition, or image classification [23].

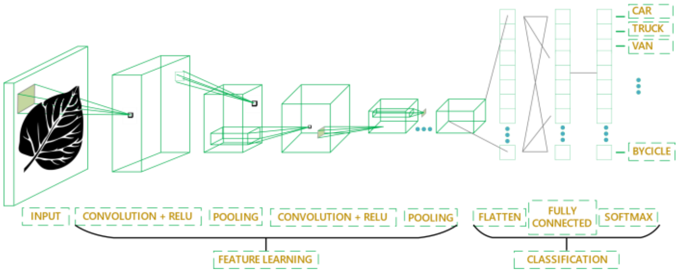

Fig. 3. Convolutional Neural Network CNN structure for disease recognition in potato leaves [25].

C. Morphological Matrix

Three stages were applied for the elaboration of the morphological matrix:

- Stage 1: The most relevant and pertinent parameters were identified and characterized; ten parameters were estimated. They are shown in the second row (Function) of Table I.
- Stage 2: The best variations for each characterized parameter of the possible solutions were evaluated and mentioned. They are shown in Table I for options A, B and C.
- Stage 3: Once the variations were identified, the combination of the possible solutions was elaborated and shown in the table as solution S1, solution S2 and solution S3.

TABLE I. MORPHOLOGICAL MATRIX

N °	Function	*Options*		
		A	***B***	***C***
1	Easy to control	1A - Manual		
2	Motion system	2A - DJI Mini SE Drone	2B - DJI Tello Boost Combo Drone	2C - DJI Mini 3 Pro Drone
3	Programming	3A - Arduino IDE	3B - Vision Software	3C - Python OpenCv
4	Vision system	4A - CMUcam3	4B - Raspberry Pi High Quality Camera	4C - Arducam OV2640 Mini Camera Module
5	Embedded system	5A - Raspberry Pi 4B	5B - Arduino Mega 2560	5C - CMUcam3
6	Maximum power and autonomy	6A - Nickel-cadmium battery	6B - Lead-acid battery	6C - Lithium battery
7	Operating system	7A - Windows	7B - Raspbian Operating System	
LEGEND		Solution S1: 1A + 2A + 3C + 4B + 5A + 6C + 7B		
		Solution S2: 1A + 2C + 3A + 4C + 5B + 6B + 7A		
		Solution S3: 1A + 2B + 3B + 4A + 5C + 6A + 7A		

The morphological matrix reflects the material options (software and hardware). The functionalities mentioned in Table 1 correspond to what is necessary for the implementation of the best solution. Three solutions were obtained, each of which varies between the form of late blight detection, the motion system to be used and the specific programming of each integrated system.

D. Project Evaluation

For this study, the VDI 2225 methodology was applied to validate the parameters and elements mentioned in the morphological matrix. The authors are qualified to perform this evaluation, as they are dedicated to image recognition and are qualified to perform this evaluation of such a tool. The solution ideas for late blight detection were subjected to a technical and economic evaluation, according to the criteria of the VDI 2225 tool.

1) Technical evaluation VDI 2225

TABLE II. TECHNICAL EVALUATION OF THE SOLUTION CONCEPT

MECHANICAL DESIGN - PRELIMINARY PROJECT EVALUATION										
TECHNICAL VALUE (Xi)										
Project title: Proof-of-concept design for identification of Late Blight on potato leaves using a UAV										
P: P: Score from 0 to 4 (Scale of values according to VDI 2225) 0 - Does not satisfy, 1 - Acceptable, 2 - Sufficient, 3 - Good, 4 - Very good (ideal); **g**: Weighted weight according to the importance of the evaluation criteria (from 1 to 5).										
Concept / project variants			***S1***		***S2***		***S3***		***Ideal gp***	
N °	**Evaluation criteria**	**g**	**p**	**gp**	**p**	**gp**	**p**	**gp**	**p**	**gp**
1	Use	5	4	20	3	15	4	20	4	20
2	Security	5	4	20	2	10	3	15	4	20
3	Robustness	5	3	15	2	10	4	20	4	20
4	Ease of installation	5	3	15	4	20	2	10	4	20
5	Maintenance	5	3	15	3	15	2	10	4	20
6	Ease of operation	5	3	15	3	15	2	10	4	20
7	System stability	5	4	20	2	10	4	20	4	20
Maximum score		35	24	120	19	95	21	105	28	140
Technical value Xi			0,86		0,68		0,75		1,00	

In Table II of the technical evaluation, it was obtained that in the criterion of use, S1 has an ideal score of four points, S2 obtained a sufficient score of three points and S3 obtained an ideal score of four points, giving us to understand that, for the management and usefulness of the materials for the design of the late blight detection system, giving us to understand that the elements of the solutions S1 and S3 are ideal for future implementation. In addition, the ideal value to obtain an ideal solution is 140 points. Therefore, the solution that is closest to this value is solution S1 with 120 points, compared to solution S2 with 95 points and solution S3 with 105 points, which are far from the value of the ideal solution. It is also observed that in the technical evaluation Xi, the highest value is 0.86, which shows that the technical evaluation solution S1 is the most optimal for the development of the research.

2) *Economic evaluation VDI 2225*

TABLE III. ECONOMIC EVALUATION OF THE SOLUTION CONCEPT

MECHANICAL DESIGN - PRELIMINARY PROJECT EVALUATION										
ECONOMIC VALUE (Yi)										
Project title: Proof-of-concept design for identification of Late Blight on potato leaves using a UAV										
P: P: Score from 0 to 4 (Scale of values according to VDI 2225) 0 - Does not satisfy, 1 - Acceptable, 2 - Sufficient, 3 - Good, 4 - Very good (ideal); **g**: Weighted weight according to the importance of the evaluation criteria (from 1 to 5).										
Concept / project variants			***S1***		***S2***		***S3***		***Ideal gp***	
N°	**Evaluation criteria**	**g**	**p**	**gp**	**p**	**gP**	**p**	**gp**	**p**	**gp**
1	Number of pieces	5	3	15	3	15	3	15	4	20
2	Procurement of materials	5	4	20	4	20	3	15	4	20
3	Design cost	5	4	20	3	15	3	15	4	20
4	Cost of technology	5	3	15	3	15	2	10	4	20
5	Ease of maintenance	5	4	20	3	15	4	20	4	20
6	Cost of operation	5	3	15	3	15	3	15	4	20
Maximum score		30	21	105	19	95	18	90	24	120
Economic value Yi			0,88		0,79		0,75		1,00	

In the economic evaluation, Table III. It is observed that, with respect to the cost designation criterion, solutions S2 and S3 have a sufficient score of three points, while S1 has an ideal score of 4 points, which implies that solution S1 has a greater advantage with respect to the acquisition of materials with an affordable cost. It is also observed that the highest value of the economic evaluation Yi is 0.88, which shows that solution S1 is the most optimal because it is closer in score to the ideal solution of 120 points.

3) *Diagram of technical-economic evaluation in VDI 2225 standard*

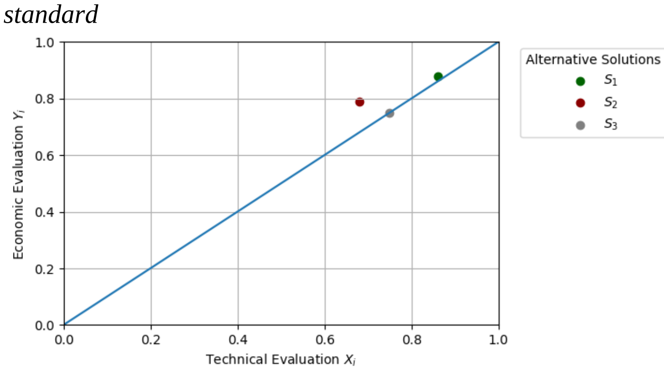

Fig. 4. Technical and economic evaluation diagram in the VDI 2225 standard.

Figure 4 shows that the evaluation diagram with the highest technical and economic value, closest to the characteristic line of the diagram, is solution S1 with a technical value Xi of 0.86 and an economic value Yi of 0.88, which leads to the conclusion that it is an optimal solution.

E. *Selection of Materials*

1) *Embedded system*

An embedded system (ES) is a computer system formulated to perform real-time operations [26]; typically, the core of an embedded system is a microcontroller or microprocessor [27]. It is designed for certain special needs and to reduce costs [26].

The developed design emphasizes the recognition of Late Blight identification on potato leaves; it is divided into specific stages for a specification. The difficulty of designing an embedded system in its development phase requires the simultaneous balance of software and hardware [29].

a) Selection of embedded system

The system will use a microprocessor to load the late blight identification algorithm program. The Raspberry Pi 4 Model B was developed by the Raspberry Pi Foundation, the Raspberry Pi 4 model with 4 GB of DDR4 RAM, contains a 64-bit 1.5 GHz quad-core ARM-Cortex A72 1.5 GHz processor [32]. The 4 GB Raspberry Pi 4B has a MIPI CSI port that facilitates the connection of a camera.

2) *Software*

a) Python

Python is a modern object-oriented, imperative programming language developed in 1990 by author Guido van Rossum [29]. The Python programming language has many relevant features, is customizable and executable on most operating systems, and offers freely available libraries [30]. The programming algorithm for the late blight identification system is developed in the Python programming language. The code is loaded into the Raspberry Pi 4 Model B microprocessor and coupled to the UAV from a camera to perform late blight recognition on potato crop leaves. Image classification and detection using the OpenCV library is compatible with several operating systems as well as the Python programming language. OpenCV is a computer vision library in which computer vision-based algorithms can be realized [31].

b) Flow Diagram

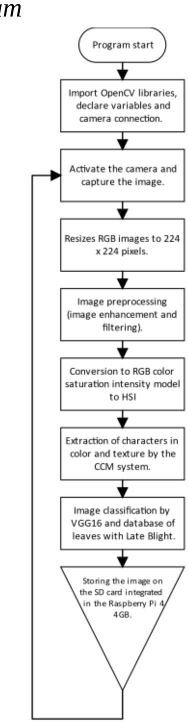

Fig. 5. Late blight detection algorithm flowchart.

Figure 5 shows the late blight detection algorithm and the processes to follow to have the programming in its entirety, this algorithm is programmed in Raspbian OS with the latest version of Python and Open CV. Image acquisition is every five seconds while personnel control the drone flight at a moderate speed. The flight height of the drone is approximately 30 centimeters above the potato leaves.

3) Hardware

a) Camera selection

For the development of late blight recognition, image resolution, optical characteristics and communication must be taken into account.

The Raspberry Pi High Quality, developed in 2020 by the Raspberry Pi foundation, has a resolution of 12.3 megapixels [33]. It has an integrated IR-cut filter that helps capture images with the truest possible colors [33]. The camera connects to the Raspberry Pi via a CSI (Serial Camera Interface) ribbon cable, which facilitates powering the camera and transferring data to the microprocessor.

b) Drone Selection

A drone that flies over the crop is used to detect late blight in potato crops. The DJI Mini SE drone has a flight duration of 30 min; the battery has a capacity of 2,600 mAh and finally, it has a wind resistance of 38.5 km/h [34]. The wind resistance of the drone is crucial for its application at extreme altitudes.

c) Battery selection

Operation of the Raspberry Pi 4 4 GB requires a five-volt, three-amp power supply [32]. The suitable battery is a five-volt, three-amp lithium battery that has a power consumption of 15 watts, including the Raspberry Pi High Quality camera used in the work.

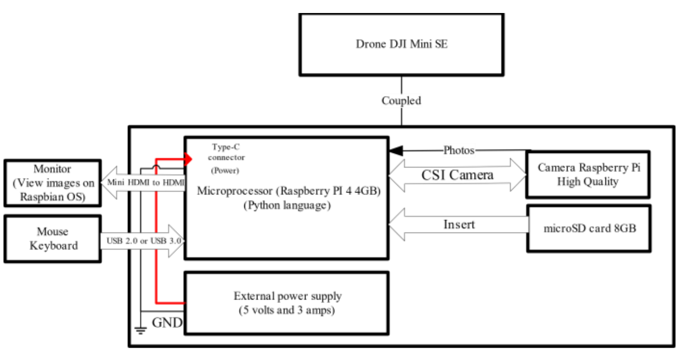

Fig. 6. Schematic diagram of the late blight identification system.

d) Schematic Diagram

The connection of the components is shown in the schematic diagram (Figure 6). The Raspberry Pi 4 4GB is powered by an external battery, the Raspberry Pi High Quality camera is powered by the CSI connection. The sending of the photos will be through a CSI flat cable to the microprocessor. This system is coupled to the DJI Mini SE drone for manual control of the drone. The Late Blight recognition algorithm is preprogrammed in the Raspian OS operating system located on the microprocessor inside an SD card.

The images with the recognition of Late Blight on potato leaves are stored on the micro-SD card installed in the Raspberry Pi 4 4GB, the results of the detection images are observed on a monitor with a mini-HDMI to HDMI cable, also to facilitate the manipulation of the results in the OS are added some peripherals such as: mouse with USB 2.0 or USB 3.0 connection and a keyboard with USB 2.0 or USB 3.0 connection.

IV. Discussion

In the development of this research, an evaluation of the solutions was carried out using certain criteria of the VDI 2225 tool. In the economic evaluation, three economic values Yi were obtained, solution S1 with a value of 0.88; solution S2 with a value of 0.79 and solution S3 with a value of 0.75, demonstrating that solution S1 is economically viable for obtaining its inputs. As for the technical evaluation, Xi the results for solution S1 is 0.86, solution S2 with a value of 0.68 and solution S3 with a value of 0.75, demonstrating that solution S1 is optimal for its next implementation. These results show that solution S1 has higher efficiency and acceptability for the design of late blight identification on potato leaves.

V. Results

The algorithm design (Fig. 5) reflects the sequential steps for late blight detection, which is programmed on the same microprocessor with a pre-installation of the chosen operating system Raspbian OS and the Python programming language plus its Open CV machine vision library. The schematic diagram (Fig. 6) includes all the materials necessary for the implementation of the potato leaf late blight identification system.

VI. Conclusions

The development of this paper resulted in the design of a proof-of-concept system for the identification of late blight on potato leaves coupled to a UAV based on an evaluation of the selection of optimal solutions. In addition, image processing steps were applied for late blight detection and a VGG16 convolutional neural network was applied for image classification.

Also, for the image detection process, a flowchart based on ANSI standards, which facilitates the understanding of the disease identification process was developed in Python language, and a schematic diagram of the integrated system was developed based on the evaluation and selection of the optimal solution S1.

Finally, the triple diamond design methodology was used for this article; however, it was applied up to the second diamond because it is a proof of concept for the identification of late blight on potato leaves coupled to the UAV. It is worth mentioning that the second diamond is the design of a proof of concept and is to leave everything ready for its next application which would be the third diamond.

VII. Future work

The present work opens new research areas, one of them is to complete the third diamond of the applied methodology which is the construction and implementation of the design of the Late Blight identification system coupled to a UAV through the schematic diagram and flowchart guidance. Another future research is to perform the storage of the identified Late Blight images to be sent to a private website for informational purposes for citizens.

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