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A CASE-STUDY VISION

Computer vision system for categorizing and weighing loads of cocoa production in the Ariari region

Sistema de visión computarizada para categorizar y pesar cargas de la producción de cacao en la región del Ariari

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ABSTRACT

This project focuses on developing and implementing an intelligent prototype for the classification of cacao fruits in the Ariari region, based on their size and ripeness. The researchers created an automated solution that addresses common issues in the classification and weighing of the fruits. The prototype uses a 1 HP motor to transport the fruits from the hopper to the classification area, where a Full HD camera captures detailed images from various angles. These images are analyzed by specialized software that classifies the fruits according to their size and ripeness, reducing classification errors and improving accuracy. The automation also enhances working conditions by reducing manual intervention, optimizing the process, and lowering operational costs. By implementing this system, companies can meet international quality standards, facilitating exports and improving their global competitiveness. This not only increases the productivity and quality of the cacao but also has the potential to boost revenues and strengthen the companies' positions within their sector.

RESUMEN

Este proyecto se centra en desarrollar e implementar un prototipo inteligente para la clasificación de frutos de cacao en la región del Ariari, basado en su tamaño y madurez. Los investigadores crearon una solución automatizada que resuelve problemas comunes en la clasificación y pesaje de los frutos. El prototipo utiliza un motor de 1 HP para transportar los frutos desde la tolva hasta la zona de clasificación, donde una cámara Full HD captura imágenes detalladas desde varios ángulos. Estas imágenes son analizadas por un software especializado que clasifica los frutos según su tamaño y madurez, reduciendo errores de clasificación y

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mejorando la precisión. La automatización también mejora las condiciones laborales al reducir la intervención manual, optimizando el proceso y disminuyendo los costos operativos. Al implementar este sistema las empresas pueden cumplir con estándares internacionales de calidad, facilitando la exportación y mejorando su competitividad global. Esto no solo incrementa la productividad y calidad del cacao, sino que también tiene el potencial de aumentar los ingresos y fortalecer la posición de las empresas en su sector.

1. Introduction

The production of cacao is undoubtedly one of the rural foundations of the Colombian economy, providing resources to thousands of families in remote regions in the departments of Santander, Tolima, Cesar, Norte de Santander, Arauca, Huila, Chocó, Meta, Nariño, Antioquia, Caquetá, Córdoba, Valle del Cauca, Guaviare, Vichada, and Magdalena [1] [2] [3]. Cacao has diverse properties, especially when made into chocolate, with multiple health benefits [4]. The Altillanura in Meta is a cacao-producing region in the Orinoquía. It is the fourth-largest cacao producer in the country, with 10,600 hectares and 12,300 tons of dry grain [5] [6].

This region has technological support for soil and water characterization and provides recommendations for soil management. However, specific technologies for cultivating cacao here are lacking [7] [8] [9]. Cacao production in Colombia has evolved to increase international competitiveness. Small producers do not benefit from the concentration and large-scale production [10] [11]. Investment in cacao plants is crucial for defining the market. Cooperatives and producer associations benefit from this [12].

The classification of production using computer vision has become an increasingly important process in applied research within industry and commerce. Evidence of this includes the well-known large-scale data collection and image analysis techniques, such as LSVRC [13].

The developments created through CNNs are a type of neural network that has become a popular algorithm for solving image classification, following the surge in the last decade in the field of computer vision. This is due to their ability to identify visual patterns and classify objects with high accuracy [14].

Since then, numerous automated and computer vision developments have been created with the aim of automating repetitive, tedious, and dangerous tasks in the production processes of various sectors of the agroindustry, such as disease recognition in crops [15], spectral analysis with drones [16], livestock unit counting [17], weed detection in crops [18], disinfection and drying of unpackaged food [19], agricultural irrigation prescription based on sensor networks and crop modeling [20], remote-controlled crops [21], and Semigar greenhouse automation [22].

The state of the art even includes applications that emulate human behavior in the categorization and weighing of loads, bio-inspired by the human eye's ability to gauge an object's proportions and volume [23]. However, the fundamental task in the agro-food industry is the identification of fruit ripeness, categorization by class, and weighing [24]. This has driven the creation and development of computer vision systems.

The Faculty of Basic Sciences and Engineering at the Universidad de Los Llanos has developed a Computer Vision System for Categorizing and Weighing Loads in Cacao Production in the Colombian Altillanura. This initiative contributes to the development of production under the concept of "Cacao de Origen," cultivated in the highland municipalities of the Ariari region in the department of Meta.

New technologies were used to process information collected at points of interest, transmitting values to a central control. A camera and software analyzed the loads visually using computer vision, creating a classification program to detect cacao load categories.

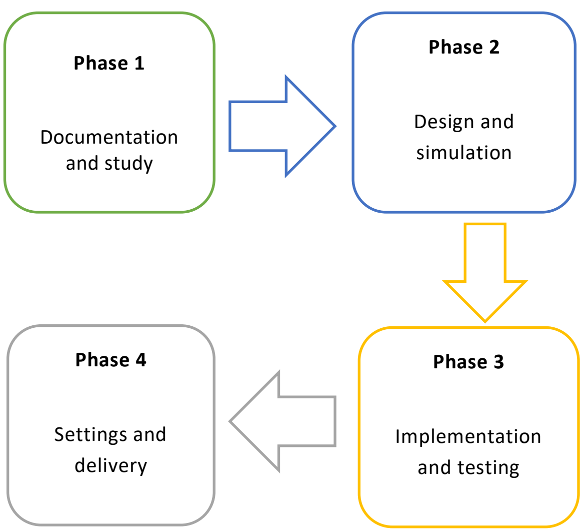
The information was sent to the equipment, and a control system was generated on a server for real-time decision-making. Human-machine interfaces were configured as web applications accessible from any device connected to the network, improving production efficiency and minimizing operational costs.

The document is structured into four sections: the first is the present introduction, the second covers the methods and materials used, the third section deals with the results analysis, and the fourth section presents the conclusions drawn.

2. Materials and Methods

The methodology used for the implementation of the cacao classification system is divided into four phases, which are developed sequentially following the order shown in Figure 1.

Figure 1. Diagram of the Developed Methodology.



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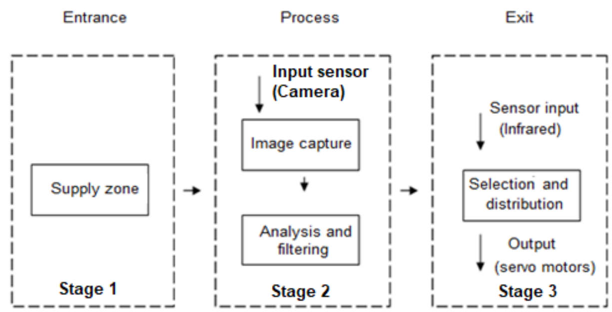
The designed system is oriented towards the scheme outlined in Figure 2.

Figure 2. Block Diagram of the System.



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Stage 1 Supply: In this stage, the fruits are placed into a supply hopper and fall onto the conveyor belt rollers.

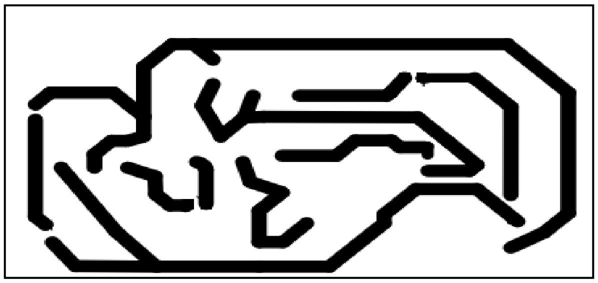
Stage 2 Analysis: The rollers transport the fruits to a closed section equipped with an HD camera for capturing images of the fruit from various angles. A pre-designed software that performs the appropriate classification analyzes these images.

Stage 3 Selection: Finally, the fruit passes through a section with infrared barrier sensors that, upon detecting the pre-classified fruit, activate the device that opens the door to the dispatch trays.

2.1. Motor Speed Control

The motor speed control was implemented using an RC circuit and a thyristor (SCR). The RC circuit creates a phase shift between the input voltage and the voltage across the capacitor, which supplies current to the thyristor gate. The power delivered to the load is controlled by varying a potentiometer; the resistive value can be adjusted to produce a variable phase shift, which in turn makes the power delivery to the load adjustable. The diode in the thyristor gate is used to block the gate voltage during the negative cycle (from 180° to 360°). After experimenting with the circuit on a breadboard and adjusting some component values, the printed circuit board was designed. The circuit is shown in Figure 3.

Figure 3. Circuit Layout Model Prepared for Printing on Bakelite.



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For the implementation of the pulley system used in the sorting machine that drives the rollers, the following simple relationship shown in was considered (1):

$$R = \frac{D}{d} = \frac{n}{N}; D = \frac{(d * n)}{N};$$
$$d = \frac{(D*N)}{N}; N = \frac{(d*n)}{D}; n = \frac{(D*N)}{d} \quad (1)$$

$\therefore$ R = pulley radius of transmission;
D = *distance between the motor shaft and bearing*

d = *motor shaft diameter*;
n = *normal force at the bearing point*;

N = *required force in Newtons*

2.2. Design of the Computer Vision System

A Computer Vision (CV) system is an automated system that uses electronic devices consisting of specialized hardware and software capable of performing vision, analysis, and image interpretation tasks similar to those of a human [25]. Information acquisition is carried out using one or more cameras or sensors. The captured data is processed through algorithms, yielding results based on the required application, such as measurements, object detection, shape analysis, object counting, inspections, predictions, and more.

For the brightness control, a LED light system was installed within the analysis section. The digital sensor BH1750 was used to measure light levels. An algorithm was created to control the light intensity within the box, which affected the proper capture of photos to be processed by the software. Figure 4 shows the prototype stations and the stages of capture, pre-processing, segmentation, classification and comparison of the cocoa images with the reference ones to select the units that meet the ripening quality and weight requirement.

2.3. Data Selection and Preparation

Regarding data selection, the computer vision system is trainable. In other words, it will be able to differentiate the elements to be identified in the image through the capture of many images that allow the system to learn. However, a selection of the main features to be identified is first carried out to test and refine the implemented algorithm. The data must be provided through an image base acquired by capturing photographs with the camera, referred to as the "media" image capture flow. These images are then processed and transformed for the computer vision system.

For the development of the software responsible for digital image processing, the Python programming language was used in conjunction with the Raspberry Pi 2 board. The camera is connected to this board, which captures images of the fruits as they pass through the rollers transporting them. The software design process is described in Figure 5.

In Figure 6, you can observe what happens at the end of the processes of: image capture, conversion from RGB to HSV, and the filtering performed by the software designed for the fruit analysis stage as they pass through the classification camera.

Figure 4. Vision system for grading cocoa fruit.

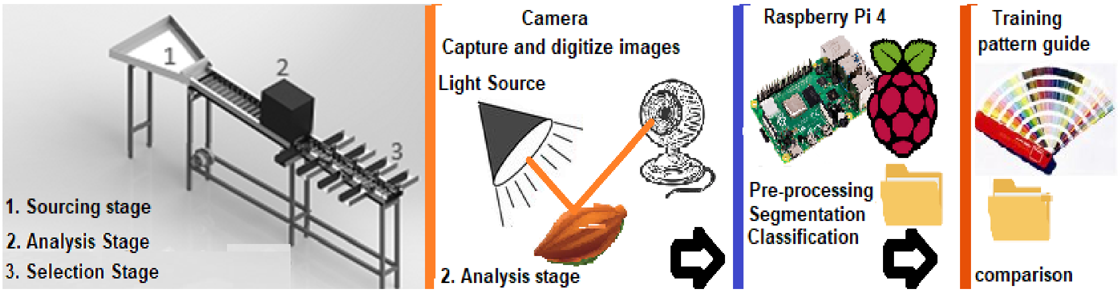

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Figure 5. Block Diagram of the Software Design.

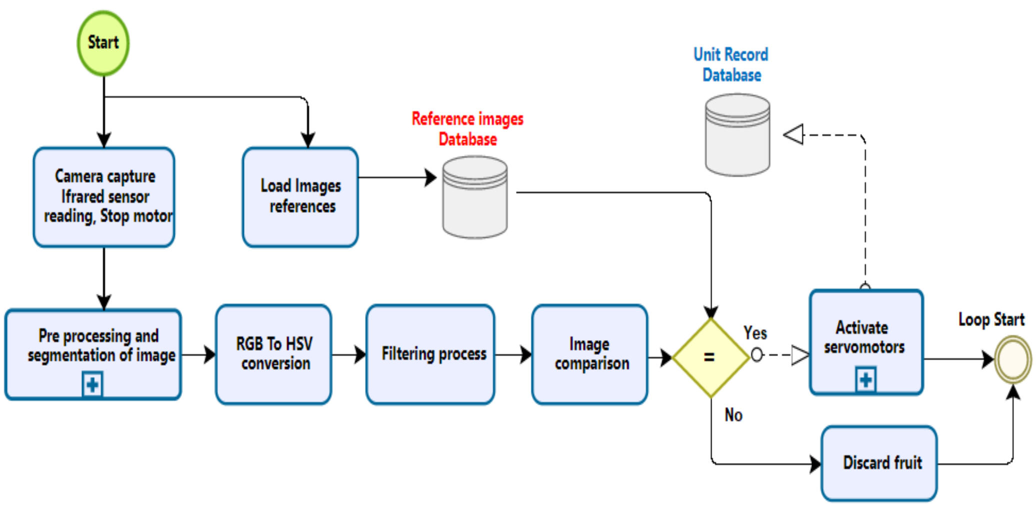

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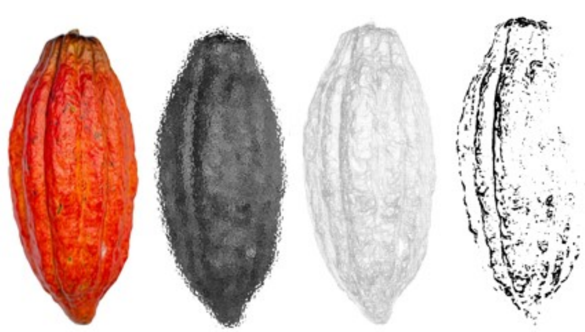
Figure 6. Input Image – RGB to HSV Conversion – Filtering Process



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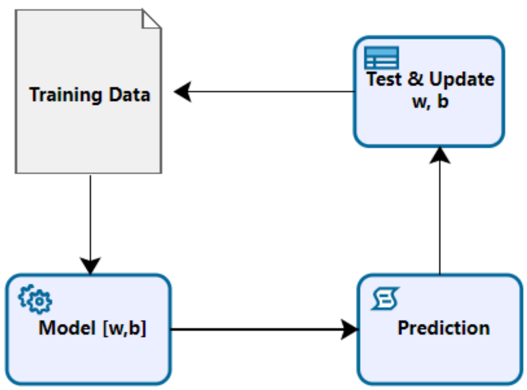
The data selection and preparation process for the computer vision system is crucial to ensure accuracy in categorizing and weighing loads in cacao production in the Altillanura region of Colombia.

2.4. Training and Validation of the Machine Learning Model

For the model used, the confusion matrix, precision, reference and registration are calculated to measure its prediction and generalization ability. Figure 7 shows the diagram of the model used. In most cases, the weight distribution is overlapping. The classified load represents 88.1% of the database, which makes the model's task difficult by favoring the most common values. However, despite the difficulties, the trained classifiers provided a measure of the quality of the fruit's ripening and classification status.

Figure 7. Model training process.



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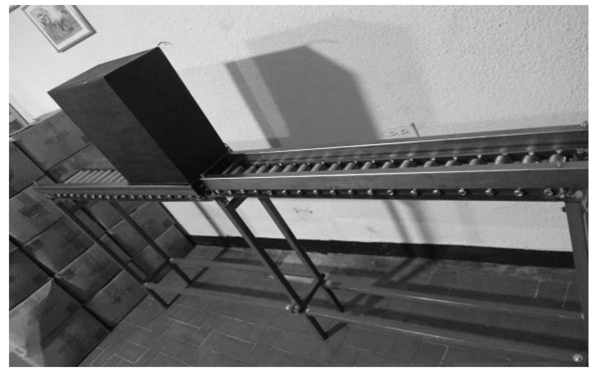
The exported values present the results of classification losses using the manual and automated fruit techniques for the best classification model, using the previously established hyper parameters. On the other hand, taking into account that weight grouping may reflect invalid results, since an aggregation criterion at the classification level was not specified in the data collection process, the detailed matrix demonstrations will classify taking into account only the matching weights, indexed with the general keys by category and maturation despite the same criteria, except one to categorize that the key would be satisfied with one value, regardless of the rest.

3. Results

Among the results of the work, the notable technical contributions and innovation in the use of digital image processing stand out. These contributions translate into greater precision and efficiency in fruit classification, which promises significant utility in the agricultural and food industry, thus contributing to optimizing resources, reducing waste and improving the quality of products, marking a milestone in the automation and improvement of processes in this crucial sector. The results are detailed below, starting with the prototype built for the validation of the system design, which can be seen in Figure 8.

Figure 8. Prototype of sorting machine built.



Source: Own.

Errors were reduced when classifying fruit by ripeness, since manual classification of fruit was tedious and tiring for the person engaged in this activity, which, together with fatigue and other associated factors, produced small errors at the time of classification.

Table 1. Record of cocoa losses during the classification and weighing process.

Load category according to its weight	Load entered for classification (kg)	Lost Manual classification (kg)	Lost Classification Automated (kg)
Extra (E)	150	6.2	1.5
Premium (P)	150	5.5	1.3
Second (S)	250	25.6	2.8
Industrial (I)	350	32.5	3.4
TOTAL	900	69.8	9.0

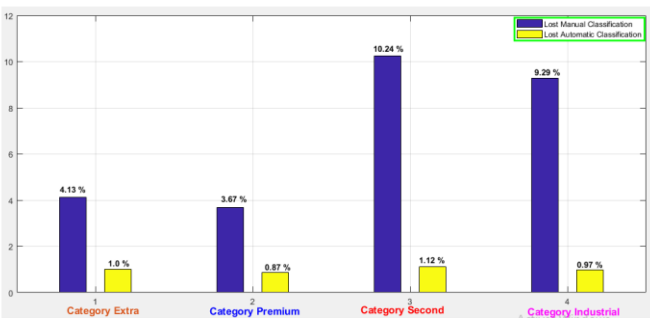
Source: Own.

As shown in Table 1, the accumulated losses with the manual classification system represent 7.75% of the total load, while with the computer vision system, this percentage was 1%.

By implementing the automated cocoa classification system, for example, it was possible to reduce classification times. For a sample of 900 kg, manual fruit classification took approximately 6 hours, while with the automated system, for the same 900 kg sample, classification was completed in a period of 1 hour and 45 minutes.

Figure 9 shows the comparison between the kilos lost due to poor selection during the classification of a sample load of 900 kg of cocoa.

Figure 9. Comparison between losses due to manual and automated classification.



Source: Own.

In Figure 9, we can observe that, for all weight categories, the automated classification system presented a substantial reduction in losses associated with poor classification of the cocoa maturity state.

4. Conclusions

The developed system is based on methodologies and utilizes cyber-physical systems, which allow for the automatic acquisition and management of information about objects of interest. In this case, the classification by categories of load and weight of cacao. The system performs image processing to identify certain patterns. The obtained information is then processed on a Raspberry Pi development board, which centers on a case-based information system and the application of digital filters. The information is sent to the cloud, allowing users to generate activity reports.

It is developed as a prototype tested in a packaging plant located in the Colombian Altillanura, using real-time computing techniques. It offers a cost-effective system due to the implementation of various modules that interconnect without needing to replace existing equipment. The automation of monitored data collection allows for minimal interference in the classification and weighing activities. This also reduces the operational risk to personnel who traditionally had to inspect the results of the initial process to identify the correct variables indicating the ripeness and weight of the load.

Each system integrated into the classification system allows the operator to accurately calibrate the size of the fruits, avoiding errors that occur when calibration is done manually.

The shape of the hopper used meets the system's supply needs, as it allows the entire volume to be filled with fruit.

Digital image processing and the implementation of digital filters have achieved minimal error in the calibration of fruit and classification by ripeness compared to other conventional methods used for such processes.

The distribution stage offers the advantage of selecting between different fruit categories based on ripeness and size characteristics, which is a distinctive advantage of the process, as it meets the commercialization standards required by exporting companies.

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