# Development of an Automated Machine for Green Coffee Beans Classification by Size and Defects

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***Abstract*—This paper presents the design and implementation of a prototype automated machine for green coffee beans classification for small agro-industries. This work responds to the need to simultaneously automate the processes of sorting by size and grading by physical defects of green coffee beans with the aim of optimizing the time and increasing the quality of the final product. Firstly, the machine classifies grains into three size ranges through a mechanical sorting system. Secondly, it has computer vision algorithms working in real time to differentiate good and defective grains. Then it has an embedded system for control along with a set of sensors and actuators and a control panel that make possible a selection of quality of green coffee beans. The results show an accuracy of 96% for sorting by size and an accuracy of 80% for grading by physical defects. The flow of coffee beans at the outlet is approximately 5 kilograms per hour. Finally, a set of conclusions and future works are presented.**

***Index Terms*—coffee bean, automated machine, sorting by size, grading by defects, computer vision**

## I. Introduction

The coffee is the second most commercialized product and one of the most consumed drinks worldwide. In South America, there are seven countries that produce coffee for domestic consumption as well as for export. Peru is an exporting country of coffee, being the Arabic coffee the main type of coffee exported, which is harvested in most of the national territory. According to the International Coffee Organization (ICO), the total production of coffee in 2015-2016 was 147 994 thousand sacks where each sack equals 60 kg of coffee. Peru contributed with 3301 thousand of sacks, being located in the tenth position of exporting countries [1].

The process of coffee production begins with the cultivation of seeds. Then, it follows the crop and pulped, in which the grains are extracted from the cherry. The fermentation and washing are then carried out in which the mucilage is removed. Drying process continues and parchment coffee grains are obtained. Subsequently, the peel is removed from the parchment coffee by friction to get green coffee beans. Thereafter, the green coffee beans are classified by size and defects so as to finally be roasted and milled.

In order to get a high-quality final product, it is necessary that the green coffee beans are properly classified before being roasted. First, it is necessary to classify by size since the roasting time varies according to the grain size. Grading by defects also results necessary since defective green coffee grains decrease the quality of the final product. The presence of fungi and diseases directly affects the color of the grain, which are commonly black and brown. Defective coffee grains represent 15% to 20% of the total production of coffee. Approximately 1.2 to 1.5 million tons per year are rejected in international markets because those grains produce undesirable flavor in drinks when they are toasted with non-defective grains [2].

In small agro-industries, the grading process by defects results inefficient because, generally, it is accomplished manually. Furthermore, with respect to the size classification process, although it is true that there are special machines, these can result too expensive for small-scale farmers. Consequently, it arises the need to design low-cost machines but at the same time efficient to classify grains by size and defects.

In the last years, there has been a significant increase in the development of automatization of the coffee grains classification process with the aim of achieving homogeneity in the products. The use of artificial vision systems has greatly increased the productivity of this process [3]. Algorithms of computer vision are developed in order to have different levels of quality according the degree of maturity, size and presence of defects [4].

Trying to cope with the limitations of small agro-industries while keeping a simple solution, a prototype machine is presented with a compact design combining mechanisms and computer vision algorithms so as to be an economically viable option and capable of perform the two classification process.

The reminder of this paper is organized as follows: the following section presents related works about both process of classification for coffee beans. In Section III, the design and implementation of the machine is described, including the conceptual design, mechanics and electronics characteristics along with the computer vision algorithm. In Section IV, the operating results of

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the machine and discussions are presented. Finally, in Section V, a set of conclusions and future work is presented.

## II. Related Work

In order to automate the coffee grading process by defects, green coffee bean conveyors were redesigned to improve the productivity performance of manual grading and reduce the cost of the process [5]. Artificial vision was then introduced in the coffee production process, algorithms were implemented for the classification of coffee beans based on color and morphological properties [6]. Color sorting is the method most used for automatic classification of fruits and vegetables that could also be applied for grading green coffee beans. First, this method captures the fruit image, then, the image is separated in RGB channels and the color is determined. Thereafter, the fruits are separated into different reservoirs through electrical actuators [7].

In some cases, this color sorting algorithm is deficient, hence, the Fast Fourier Transform (FFT) can be used as alternative to analyze grain images for classification by defects [8]. It is also possible to use Fourier Transform Infrared Spectroscopy (FTIR) in order to separate between defective and non-defective grains. Information parameters are extracted from the grain images and then a multivariate statistical analysis is performed through Principal Component Analysis (PCA) for discrimination. [9]. A more sophisticated method is to get parameters according to the physical characteristics that are obtained from grain images to be used as input data of an artificial neural network. After training the neural network, the system is capable to identify green coffee quality class [10]. Another method involves using a Gray Level Co-occurrence Matrix (CGLCM) for feature extraction of green coffee beans and then implements a Support Vector Machine (SVM) as classifier. This approach is promising as it identifies the type of defect present in a grain under twelve possible categories. [11].

These algorithms focus in separating the non-defective grains from the defective ones to ensure the quality of the final product. However, before the roasting process, it is also necessary to sort the coffee beans by size in accordance with the standards of the Specialty Coffee Association of America (SCAA), entity that regulates the exportation of green coffee beans worldwide [12]. In order to address this need, grain sorting machines are developed according to their thickness or transverse diameter. There is a machine that is based on the use of a drum with holes to filter the grains. The grains are inserted by a hopper and directed to the rotary drum. Due to the inclination of the drum, the grains advance and fall through the holes according to their size. The holes are distributed from smaller to larger diameter. Finally, the grains are deposited in different containers [13].

As described above, there exist a variety of computer vision algorithms which seek to automate the grain grading process by defects. The advantage of these algorithms is their high precision which contributes to increasing the coffee quality. Nevertheless, most of these researches are not physically implemented in machines that perform the grading process. Moreover, there are machines that with a simple mechanical design can classify coffee beans in different sizes.

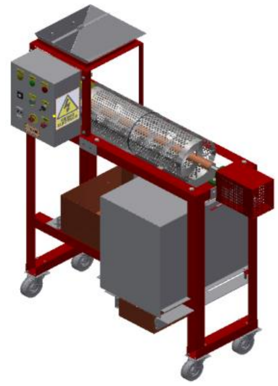

Figure 1. Proposed concept.

The proposal introduced in this paper is a prototype machine capable of simultaneously performing both classification by size and by defects targeted to small agro-industries. In this way, the time is optimized since a quality product necessarily requires that the green coffee beans got through by the two classification process.

## III. Design and Implementation

### A. Conceptual Design

At the design phase of the machine, an important aspect was to decide which subsystems were necessary and then proceed to design them. The design focused on provides the machine the capacity for sorting by size and grading by physical defects of green coffee beans. A cylindrical sieve with holes was chosen as a sorting system by size. This system classifies grains into three size ranges: small, medium, and large. A grain dosing system was installed at the entrance of the sieve to avoid it from filling.

Once classified by size, the grains should be directed to a selection area so that the defective grains are discarded. Only the medium and large grains are directed towards this area, the small grains are directly discarded as they deteriorate the quality of the final product. A vision system was designed for this selection which consists of a combination of mechanisms and cameras to differentiate good and defective grains. Finally, a control panel was designed with switches and indicators so as to easily manipulate the machine. The solution concept is shown in Fig. 1, and the specifications in Table I.

TABLE I. Machine Technical Specifications

| | |
|---|---|
| Sorting by size | Cylindrical sieve with holes |
| Grading by defects | Computer vision algorithm |
| Weight | 90Kg |
| Dimensions (m) | 1 × 0.6 × 1.2 (W × L × H) |
| Outflow | 5 kg/hour |
| Sensors | (7) Analog Infrared Sensors<br>(1) Digital Infrared Sensor<br>(2) Digital Position Encoders<br>(2) Digital cameras |
| Actuators | (2) 24 VDC Motors<br>(5) Servomotors |

| | |
|---|---|
| Materials | ASTM A36 (structure)<br>AISI 304L (cylindrical sieve) |
| Power Supply | 110-220VAC (50-60Hz) |

## B. System Design

### 1) Mechanics

The machine was designed according to the following premises: i) Compact design, ii) Removable modular system, and iii) Capacity to classify coffee beans by size and defects. In this respect, the main components are presented in Fig. 2.

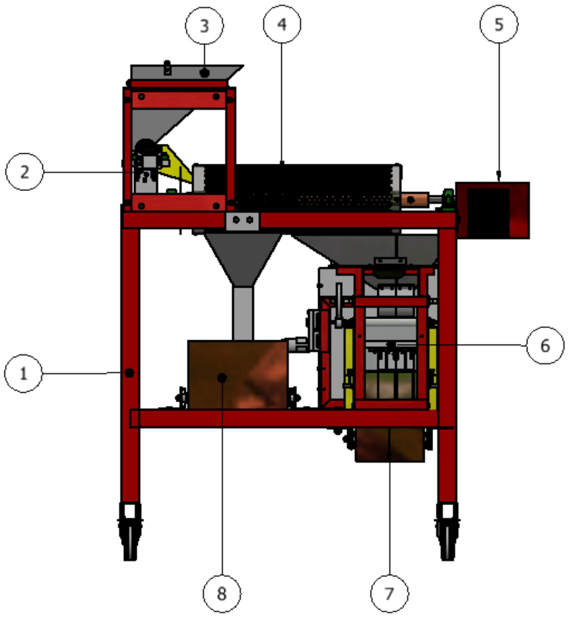


Figure 2. Main mechanical components of the machine: 1) main frame, 2) input dosing system, 3) input hopper, 4) subsystem of sorting by size, 5) DC motor, 6) subsystem of grading by defects, 7) Medium and large grains deposits, 8) small grains deposit.

In order to support the loads of all mechanical components, the main frame is made of ASTM A36 Structural Steel with 2×2 inch square profile. Then the machine has two clearly differentiated processes which are the sorting by size and the grading by defects. Below are detailed the mechanisms used for each process.

#### a) Sorting by size

The classification process by size consists of two stages. First the coffee beans are dosed at the entrance so as to have a controlled flow of grains entering the subsystem of size classification. Then the grains are sorted by size using a cylindrical sieve with holes. In the input dosing stage, a mechanism is used consisting of a servomotor coupled to an axis to move a rectangular gate. This mechanism is illustrated in Fig. 3. This gate opens and closes in same time intervals of one second to control the amount of grains entering the sieve.

In the size classification stage, a cylindrical sieve with holes is used. This sieve was made from the union of two enrolled metal sheets of 1.5 mm thickness. The first sheet has uniformly distributed holes of 4.75mm diameter, while the second has holes of diameter 6.3mm. Thus, the grains are classified into 3 size ranges: small grains fall through the first sheet, medium grains through the second sheet and large grains come out of the sieve.

$$\begin{cases} \boldsymbol{diameter < 4.75 \rightarrow small\ grains} \\ \boldsymbol{4.75 < diameter < 6.3 \rightarrow medium\ grains} \\ \boldsymbol{diameter > 6.3 \rightarrow\ large\ grains} \end{cases}$$

The complete assembly of the sorting mechanism is shown in Fig. 4. When the grains enter the cylindrical sieve, they advance along of it due to the thrust of the worm screw. Both the sieve and the worm screw are made of AISI 304L stainless steel since these components are in contact with food that are the coffee beans. Furthermore, the joining between the sieve and the worm screw is removable through bolted connection for easy maintenance.

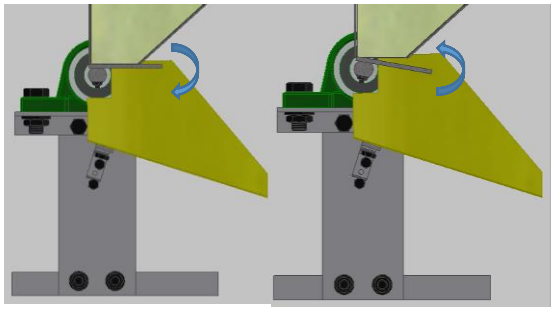

Figure 3. Gate movement for the entrance of grains.

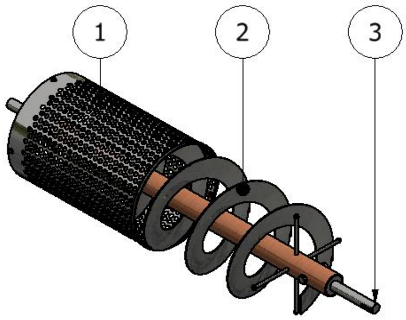


Figure 4. Components of sorting mechanism by size: 1) cylindrical sieve, 2) worm screw, 3) shaft.

#### b) Grading by physical defects

This subsystem is illustrated in Fig. 5. Medium and large grains are temporarily stored in hoppers whereas small grains are stored in a final deposit as these are discarded by deteriorating the quality of the final product. Then, the grains are dosed to fall ordered in rows towards the conveyor belt.

This intermediate dosing unit consists of a Nylon cylinder with holes distributed evenly along its circumference. Subsequently, the grains are transported by the conveyor belt and the images are captured. Then, the images are processed in real time and the grains are directed to the area of the selection pallets as shown in Fig. 6. The conveyor belt is made from translucent PVC, bonded by heat melting, which is moved by three rollers arranged triangularly. A gear transmission is used to have only one actuator to perform the movement of the conveyor belt and the intermediate dosing unit.

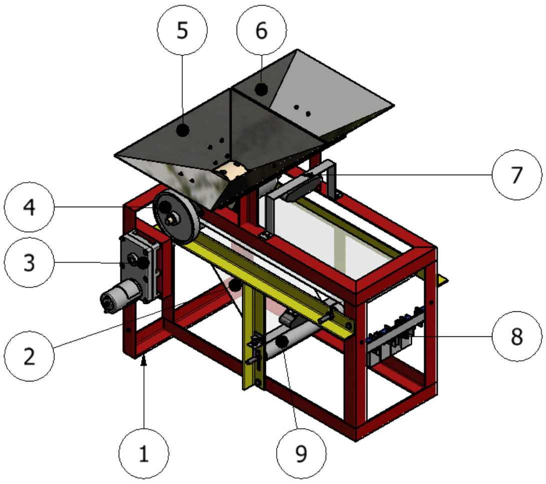


Figure 5. Subsystem of grading by defects: 1) frame, 2) conveyor belt, 3) DC motor, 4) gear transmission, 5) medium grains hopper, 6) large grains hopper, 7) upper camera, 8) arrangement of grading pallets, 9) roller.

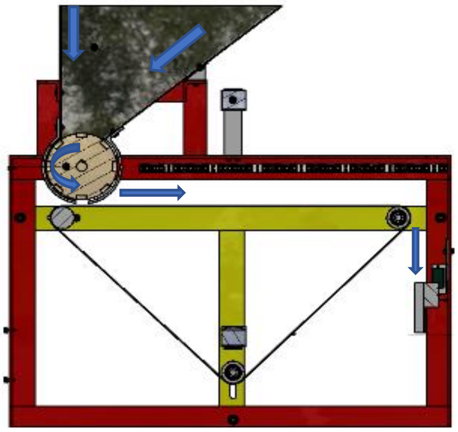

Figure 6. Movement of grains in the grading subsystem by defects.

As the conveyor belt is translucent, it is possible to capture images on both sides of the grains. After the image processing determines the grain status, the grains are separated using the array of pallets. These pallets rotate or not depending on whether the grains are good or defective. In case a grain is good, it falls directly into its deposit, otherwise the pallet rotates and changes its trajectory to fall into another deposit. Finally, this subsystem is covered and uses two LED strips for lighting. Thus, preventing the system from depending on external lighting.

2) *Electronics system*

a) *Processing unit*

The control system is composed by a microprocessor Raspberry Pi 3 whose main function is processing the vision algorithm and the data obtained from the infrared sensors. In order to send and receive signals to the actuators and sensors respectively, an Arduino Board based in the microcontroller Atmega 2560 was chosen. The communication between the Raspberry Pi and the Arduino Mega is via USB. The information flow of this system is shown in the Fig. 7.

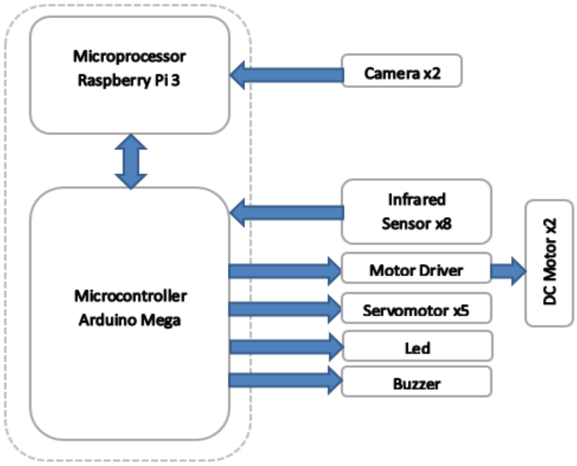


Figure 7. Block diagram.

b) *Sensors*

In order to obtain information about the filling level of the hoppers and grain deposits, seven analog infrared sensors were used. Each hopper and each deposit has an infrared sensor installed at the top to measure the filling level of coffee beans. Also, a digital infrared sensor was placed in the vision subsystem, this sensor detects if the coffee beans are in the appropriate position for the image acquisition. It should be noted that for this process, two cameras were required to capture images from both sides of the grains, located over and under the conveyor belt.

c) *Actuators*

For the purpose of separating good coffee beans from defective beans, a selection mechanism was implemented using four servomotors SG90. An extra servomotor was chosen as actuator for performing the dosing system at the machine entrance.

d) *Control Panel*

The machine has a control panel that allows the user to interact with the system. It has command controls to operate the machine and visual indicators to know the current system state. The interface is illustrated in Fig. 8 and the functions of its components are described in Table II.

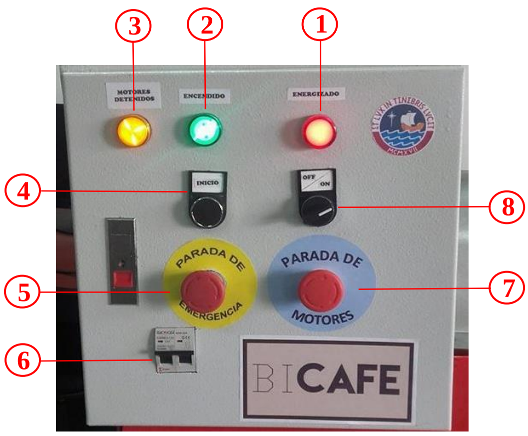


Figure 8. Control panel.

TABLE II. CONTROL PANEL FUNCTIONS

| N ° | Component | Function |
|---|---|---|
| 1 | Red Led | Indicates that the machine is energized |
| 2 | Green Led | Indicates that the machine is on |
| 3 | Yellow Led | If it is on, it means that the motors have stopped |
| 4 | Button | When is pressed, the machine starts operating |
| 5 | Button | Emergency stop |
| 6 | Thermomagnetic key | At any peak current, it is automatically deactivated and prevents current flow. |
| 7 | Button | When pressed, the motors stop moving |
| 8 | ON/OFF Switch | Used to turn the machine on or off |

*e) Motor control*

The cylindrical sieve and the conveyor belt require a DC motor, each operating at 24V. Both motors have a Hall Effect encoder to set the rotation speed. The supply and control of the motors depend on the VNH5019 Motor Driver which allows to change the rotation direction or stopping the motors if necessary.

*3) Control architecture*

The system control follows the procedure described on Fig. 9. When the machine is energized, it is turned on setting the ON/OFF switch to ON. Then the serial communication between the Raspberry and the Arduino is initialized. Once has been established connection, the machine does not begin to work until the start button is pressed. After this, all the motors and the servomotors initiate their movement depending on the signals received from the Arduino.

The Arduino constantly receives data from the analog and digital infrared sensors and then sends this information to the Raspberry. In case any hopper or deposit is full, the process will be autonomously stopped until they are emptied.

In order to capture images of the grains, these must be exactly in the middle of the cameras that are located in the center of the conveyor belt. The digital sensor is used to know the precise moment when the grains are in the desired position. Then, the images are processed in real time by the Raspberry and a four-letter arrangement is obtained. The computer vision algorithm will be explained in the next section. Thereafter, the data arrangement is sent to the Arduino in order to operate the servomotors and therefore, separate the grains into different deposits according to their state.

In case of any unexpected event, the emergency button in the control panel must be pressed. This action will de-energized all the machine and the classification will be stopped until the start button is pressed once again.

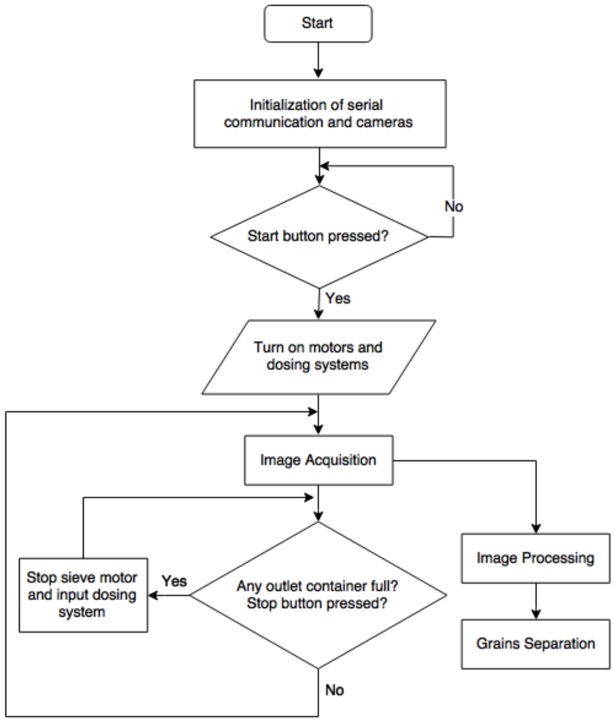


Figure 9. Flow chart.

*4) Computer vision algorithm*

An overview of the computer vision algorithm is illustrated in Fig. 10.

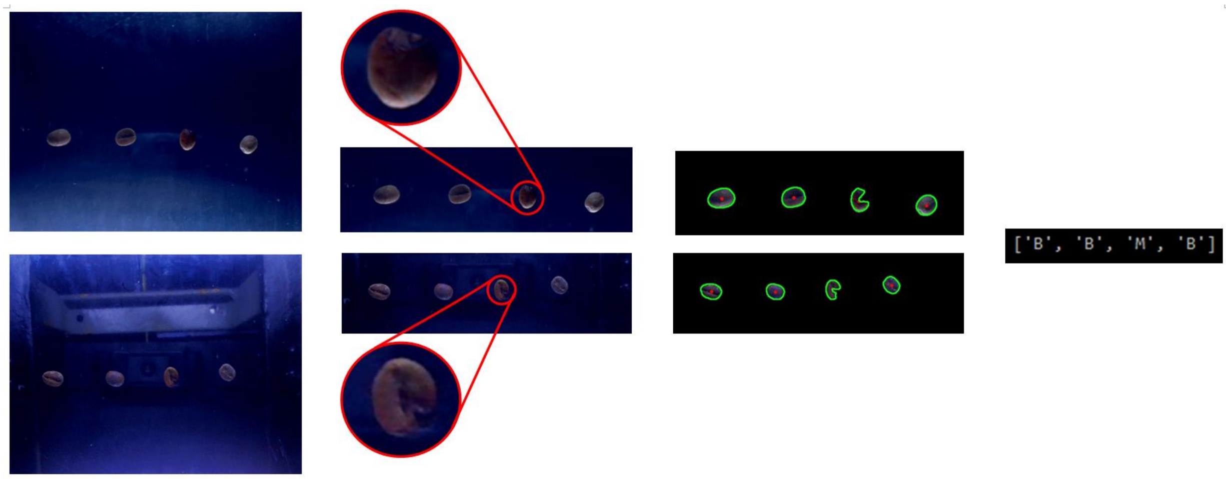


Figure 10. Overview of the computer vision algorithm. First the images are captured. Then, these images are filtered and cropped. Thereafter, the segmentation is performed on the HSV color space. Finally, defective grains are determined and an arrange of letters is generated.

*a) Image acquisition*

In order to have a more accurate analysis of the green coffee beans, it is necessary inspect both sides of each grain, since a defect or imperfection may be present just on a side of the grain and it is reason enough to conclude that the grain is defective. For this reason, there are two cameras: one located above the grains and another below. It should be noted that, in each image the number of grains varies from zero to four, because the grains come in rows from the intermediate dosing devices.

*b) Pre-processing*

All acquired images have a certain amount of noise that must be removed as it negatively affects the analysis. For this, smoothing techniques are used. The principle is based on taking a small neighborhood around a central pixel and performing mathematical operations to replace that pixel and thus eliminate the random noise. Then it is important to distinguish between the area of interest and the rest of the image to speed up the analysis. Therefore, the algorithm crop the region of interest in which only the grains are appreciated.

*c) Feature extraction*

A criterion of determining the quality of green coffee beans is based on the information about the color of the beans. Feature extraction is performed to get image parameters of coffee bean images in the term of color and shape. This requires segment the grain images and it can be performed in various color spaces such as RGB and HSV. HSV color space is chosen because it is better at places with low illumination and objects usually have brightness. Hence, first it is necessary to transform the RGB images into the HSV color space and then the segmentation is performed. Thereafter, morphological operations of dilation and erosion are carried out to have greater sharpness and relief of the images. Finally, the contours of the grains are obtained through algorithms of edge detection to get an important parameter: solidity. In this way, dark, stained and partially broken grains are detected as defectives.

$$\boldsymbol{solidity} = \frac{\boldsymbol{Contour\ Area}}{\boldsymbol{Convex\ Hull\ Area}}$$

*d) Determination of grain status*

Once the physical characteristics of the grains have been extracted, the final step is to determine if a grain is in a good condition or not.

$$\begin{cases} \boldsymbol{solidity = 0, there\ is\ no\ grain} \\ \boldsymbol{0 < solidity < 0.9, grain\ is\ defective} \\ \boldsymbol{solidity \geq 0.9, grain\ is\ good} \end{cases}$$

In each cropped image, there are from zero to four grains, hence each image is divided into four sections and the solidity parameter is obtained in each section. If in any section there is no grain, then the solidity is equal to zero. In case there is grain, if the solidity is greater than 0.9 then the grain is in a good condition, otherwise it is defective. The value of threshold was determined experimentally. This analysis is performed for both sides of each grain in order to assure the good condition of the grain as the imperfections may only appear partially. If on one side it is determined that the grain is defective, it is enough to conclude that the entire grain is defective.

Finally, a four-letter arrangement is generated, in which each letter represents the state of a grain. The letter "B" represents that there is a grain in good condition; the letter "M", a defective grain; whereas the letter "N", an empty section.

## IV. Results and Discussion

After the assembly of the machine, it was put into operation to validate its capacity to classify by size and defects as well as to evaluate its efficiency and process flow. A sample of 7000 grains was entered into the machine in each test performed. The implemented machine is illustrated in Fig. 11.


Figure 11. Implemented machine.

### A. Performance of Sorting by Size

The cylindrical sieve is actuated by a DC motor and the motor speed is controlled by the input voltage. This speed of classification affects directly the efficiency of the process.

TABLE III. Efficiencies According to Speed

| Velocity (RPM) | Efficiency in small grains (%) | Efficiency in medium grains (%) | Efficiency in large grains (%) |
|---|---|---|---|
| 10 | 91.36 | 95.51 | 96.79 |
| 25 | 94.59 | 97.24 | 96.92 |
| 40 | 89.47 | 94.83 | 96.49 |

In order to know the efficiencies of classification by each size range, tests were performed by varying the speed of rotation of the cylindrical sieve. The results are presented in Table III and illustrated in Fig. 12. It is observed that the optimal rotation speed of the sieve is 25 RPM. This speed is adequate to avoid either the sieve does not fill or the grains to move too fast and therefore poorly classified.

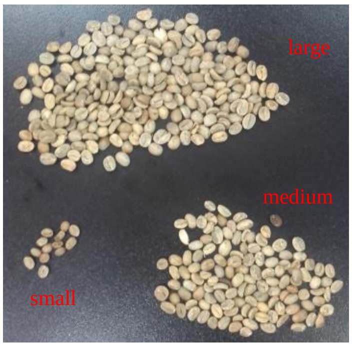


Figure 12. Result of size classification.

### B. Performance of Grading by Physical Defects

After sorting by size, the medium and large grains go through the intermediate dosing system and fall in rows towards the conveyor belt. The cameras are in the middle of the conveyor belt and the captured images are processed in real time. The processing time of the computer vision algorithm is 0.9 seconds because it processes two images at a time. Then the forward speed of the conveyor belt must allow the time between each row of grains to be at least 0.9 seconds. This time is obtained when the conveyor belt motor rotates at a speed of 30 RPM. Table IV shows the grading efficiencies for medium and large grains. The results are illustrated in Fig. 13.

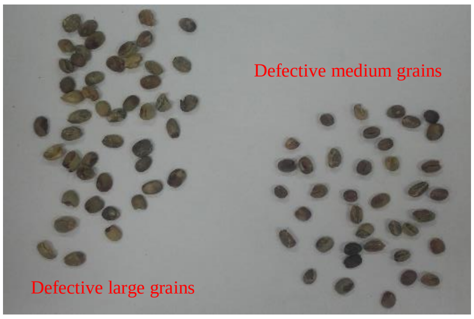


Figure 13. Result of grading by defects.

TABLE IV. GRADING EFFICIENCIES

| Grain Size | Efficiency |
|---|---|
| Medium grains | 78.39% |
| Large grains | 81.37% |

### C. Process Flow

In the final stage, the grains are separated into different deposits through mechanisms actuated by servomotors. In case the grains always are dosed in rows of four, the outflow would be of 4 grains every 0.9 seconds. This results in an optimum outflow of approximately 6.4 kilograms per hour. The machine was put into operation for four periods of one hour each so as to know the actual flow. Table V shows the amount of grain processed for each period. It is observed that there is an average outflow of 5 kilograms per hour.

TABLE V. GRAINS PER HOUR

| Test | Processed grains (Kg) |
|---|---|
| 1 | 5.15 |
| 2 | 4.74 |
| 3 | 4.91 |
| 4 | 5.05 |
| Mean | 4.96 |

## V. CONCLUSIONS AND FUTURE WORK

This paper presented the design, implementation and evaluation of a machine that can simultaneously perform the green coffee beans classification by size and by defects. This machine operates automatically with slight human intervention, and its performance and compact size makes it a potential option for small agro-industries. Moreover, it has been demonstrated that it is possible to physically implement computer vision algorithms to work in real time for the classification process.

For future work, more advanced computer vision algorithms can be implemented for improving the grading efficiency. In addition, an embedded system with higher processing speed can be placed along with high-speed cameras so as to increase the processing flow of the machine and to reach flows close to tons per hour.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

Grover Susanibar, Jorge Ramirez and Cesar Vera designed and manufactured the coffee machine; Jorge Ramirez, Jennifer Sanchez and Renzo Ramirez conducted the research; Grover Susanibar, Jennifer Sanchez and Renzo Ramirez conceived and designed the experiments; Grover Susanibar, Jorge Ramirez, Jennifer Sanchez wrote the paper under the supervision of Dante Arroyo; all authors had approved the final version.

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