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ARTICLE

Implementation of an Automated *Solanum Tuberosum* Grading System using Image Processing

Implementación de un sistema automatizado de clasificación de *Solanum Tuberosum* mediante procesamiento de imágenes

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Abstract

Automated vision systems are used as an effective solution to improve accuracy in objects inspection. However, the transition from manual sorting methods to automated systems has been slow due to factors such as the size and shape of the objects to be inspected. In the food industry, tubers represent a challenge for vision systems due to their high dimensional and morphological variability.

This paper presents the design and implementation of an automated system for sorting *Solanum tuberosum* (potato) based on machine vision and image processing technologies. The system employs a low-cost camera together with an algorithm developed in LabVIEW™, which allows determining the size of tubers in a production line. Sorting is carried out by means of a servo-driven sorting mechanism, achieving greater accuracy and efficiency compared to traditional manual methods.

A controlled lighting system was implemented to optimize the quality of the captured images, which allowed for a significant reduction in sorting errors. The results showed a 260% increase in production capacity and a 75% reduction in the error rate, validating the effectiveness of the proposed solution to improve both productivity and process quality in the food industry. In addition, the system offers a high level of flexibility and safety in operation.

By improving potato grading efficiency and reducing the need for manual intervention, a return on investment is anticipated, as well as a positive impact on process responsiveness, which could lead to an increase in product demand.

Index terms: Automatic classifier, image processing, machine vision, LabVIEW™, automation.

Resumen

Los sistemas de visión automatizada se emplean como una solución eficaz para mejorar la precisión en la inspección de objetos. Sin embargo, la transición de métodos manuales de clasificación a sistemas automáticos ha sido lenta debido a factores como el tamaño y la forma de los objetos a inspeccionar. En la industria alimentaria, los tubérculos representan un desafío para los sistemas de visión debido a su gran variabilidad dimensional y morfológica.

Este artículo presenta el diseño e implementación de un sistema automatizado para la clasificación de *Solanum tuberosum* (papa) basado en tecnologías de visión artificial y procesamiento de imágenes. El sistema emplea una cámara de bajo costo junto con un algoritmo desarrollado en LabVIEW™, que permite determinar el tamaño de los tubérculos en una línea de producción. La clasificación se lleva a cabo mediante un mecanismo separador activado por servomotores, logrando una mayor precisión y eficiencia en comparación con los métodos manuales tradicionales.

Se implementó un sistema de iluminación controlada para optimizar la calidad de las imágenes capturadas, lo que permitió reducir significativamente los errores en la clasificación. Los resultados mostraron un incremento del 260% en la capacidad de producción y una reducción del 75% en la tasa de errores, validando la efectividad de la solución propuesta para mejorar tanto la productividad como la calidad del proceso en la industria alimentaria. Además, el sistema ofrece un alto nivel de flexibilidad y seguridad en su operación.

Al mejorar la eficiencia en la clasificación de papas y reducir la necesidad de intervención manual, se anticipa una rápida recuperación de la inversión, así como un impacto positivo en la capacidad de respuesta del proceso, lo que podría llevar a un aumento en la demanda del producto.

Palabras clave: Clasificación automática, procesamiento de imágenes, visión artificial, LabVIEW™, automatización.

I. Introduction

Nowadays, vision systems represent adaptive solutions for product inspection in almost all industry sectors, from automotive to pharmaceutical [1]. Image processing systems basically consist of the automatic deduction of the structure and properties of a three-dimensional, possibly dynamic, system from one or more two-dimensional images. In this area of knowledge, concepts from color physics, optics, electronics, geometry, algorithms and computer systems are used.

Automated produce sorting using machine vision represents a promising solution to address the challenges of efficiency, accuracy, and scalability in food inspection [2]. This field integrates technologies such as digital cameras, image processing algorithms, and automated control to sort produce based on physical characteristics such as size, shape, color, and surface defects [3]. In recent years, machine vision systems have become a key tool for automating agricultural processes [4]. According to [5], these technologies have found applications in pest detection, crop classification and quality assessment, highlighting their ability to handle large volumes of data in real time. In the specific case of tubers such as potato, the high dimensional and morphological variability represents an important challenge. In [6] it was identified that, without precise illumination control and robust contour analysis techniques, systems tend to fail in uncontrolled environments.

In terms of advanced techniques, hybrid methods have gained relevance. In [7], an approach combining illumination enhancement techniques, contour-based segmentation algorithms and machine learning was proposed to classify irregularly shaped products. This approach has shown significant improvements in accuracy, although it increases system complexity and computational requirements.

An image is a two-dimensional representation of a three-dimensional world scene. The image is the result of the acquisition of a signal provided by a sensor, in this case a camera, which converts information from the electromagnetic spectrum into numerical encodings [8]. Generically, a digital image is defined as a matrix (or vector) of dimensions $n\, x\, m$, containing a discrete value that quantifies the level of information of the corresponding element, represented with a finite number of bits [9]. Each of these discrete elements is called a pixel and generally contains the illumination level or color of a point in the scene [10].

In recent years, machine vision systems have proven to be a fundamental tool in the industrial field, particularly in the automation of inspection and sorting processes. These systems are adapted to the specific needs of each application and are used in sectors as diverse as the automotive, pharmaceutical and food industries.

Image processing systems group a set of elements such as illumination sources, scene media, filters or diffusers, and sensors [11]. Fig. 1 schematizes the basic elements of an image processing system.

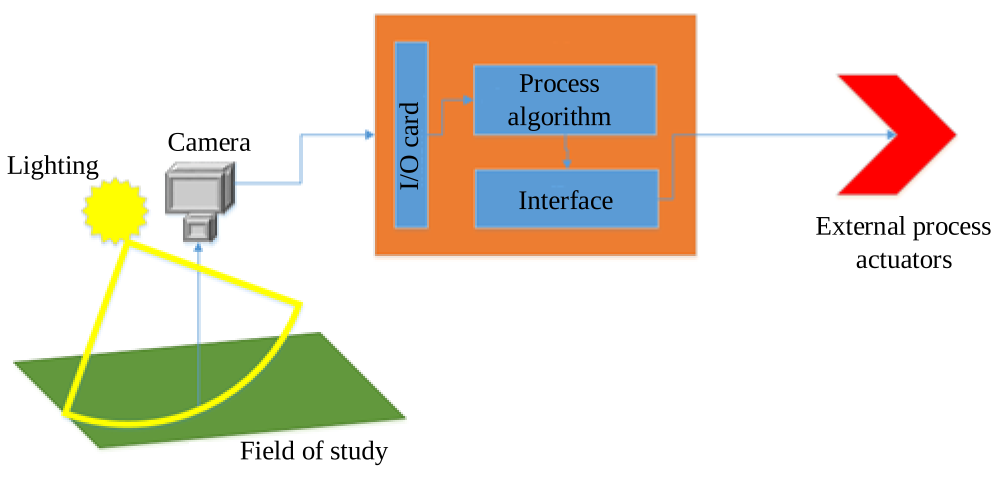

Fig. 1. Basic diagram of an image processing system.

Proper illumination is vital to obtain a correct image in which there are no saturated areas or shadows hiding information within the image. To match the vision system to the application, the following parameters need to be considered: field of view, resolution, distance between the camera and the object, and depth of field [12].

In the food industry, the grading of products such as tubers represents a challenge due to the variability in size and shape of the tubers [13]. Traditional manual inspection methods are inefficient and prone to errors, generating operator fatigue and decreasing productivity. Faced with this problem, the implementation of automated vision systems is presented as a viable solution, improving sorting accuracy and reducing the workload [14].

This paper describes the design and implementation of an automated potato grading system based on image processing, using technologies such as Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW™) and low-cost cameras. The main objective is to optimize the size separation process, ensuring accurate and efficient grading, minimizing errors and increasing productivity in the plant.

II. METHODOLOGY

The design of the automated potato sizing system was based on a detailed analysis of the current condition and improvement needs for the case study. The current sorting process is carried out manually by three workers who separate the product according to size. This process is inefficient and error prone due to fatigue and lack of visual accuracy. The need was identified to automate the inspection and separation of the product using an artificial vision system to reduce the workload and increase accuracy.

An average of 10 Tons of potatoes are evaluated weekly in an area of 32 m^2 defined within the building. There is a hopper with a capacity of 700 kg, which is filled with the product for distribution to a 4 m long conveyor belt, where it is inspected and classified manually. For the classification system, the potato is considered in a simplified way as an oval geometric shape. The system is based on two separation criteria, the first criterion considers a major axis with a value exceeding 7 cm. The second criterion corresponds to a major axis with a range of 0 to 7 cm. Fig. 2 shows a sample of the potatoes found in the warehouse and their dimensions. It should be noted that 7 out of 10 potatoes are large, which means that the classification is based on the fact that the majority of the product is large.

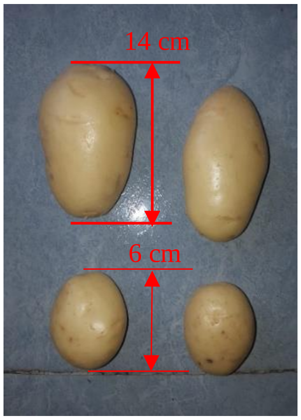

Fig. 2. Sample product and average measurements.

Given that this is a product with variable dimensions and shapes, it is not possible to determine precisely the quantity of potatoes evaluated per minute, but it is estimated that to cover the 10 tons per week, each worker sorts an average of 1 kg per minute.

A. Proosed solution

Several alternatives to automate the process were evaluated, and it was decided to implement an image processing system to analyze the size of the potatoes according to their contours. This system is complemented with a separating mechanism driven by geared motors.

The integration of the proposed prototype involves five important units: Dispensing mechanism and conveyor belt, darkroom and image acquisition and processing system, separating mechanism, control board and power stage. Fig. 3 shows the schematic of these units. For the conveyor belt drive, a Bosch geared motor was chosen, which meets the power and power supply requirements of the system. This motor can provide the necessary force to move the potatoes along the belt without compromising the efficiency of the system. A Logitech C920 HD Pro camera was used, which offers Full HD 1080p recording and is compatible with the LabVIEW™ image acquisition system. In addition, it has zoom, brightness and contrast control, as well as a high-speed USB 3.0 connection, which benefits data transmission to the computer.

LabVIEW™ was selected for this project because of its superior technical capabilities for real-time data acquisition and processing applications. It offers direct hardware integration and optimized algorithms for real-time analysis with a latency of 50 ms per image. Compared to low-cost platforms, LabVIEW™ reduces implementation time by 30% and stands out for its compatibility with industry-standard protocols such as RS232, Modbus and TCP/IP. Its graphical approach simplifies parallel tasks, such as simultaneous image processing and actuator control, ensuring stability and efficiency. Although expensive to license, its advantages justify the investment for industrial applications where speed and stability are essential.

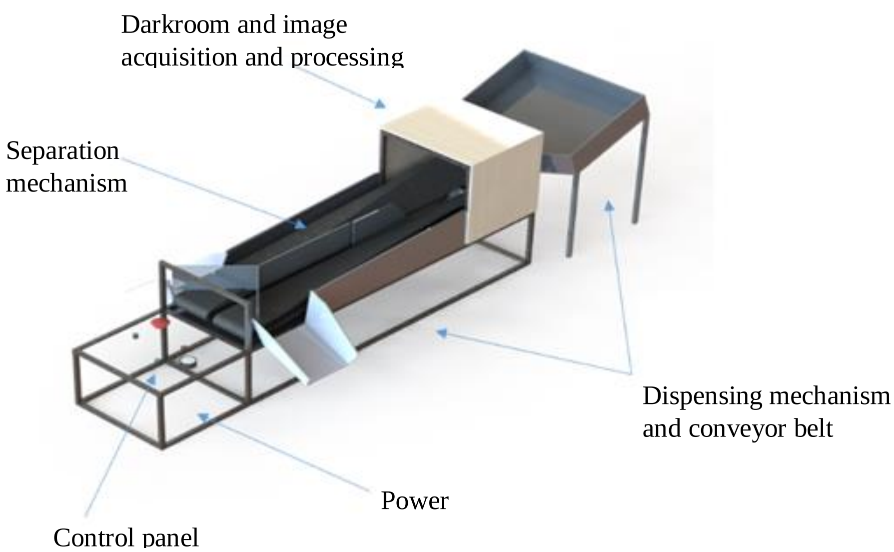

Fig. 3. Potato inspection and grading system scheme.

Inside the darkroom, the camera is placed at a height of 35 cm from the observation plane, pointing at a perpendicular angle to the plane where the product to be evaluated flows. The system has a control panel and a Human Machine Interface (HMI) that allows data processing and actuator control. The HMI includes options to adjust the size of the potatoes to be graded and to monitor the system status in real time. This solution allows rapid development of image processing applications and control of data acquisition from the camera and actuators. Proper image acquisition depends on an adequate lighting system. A 3 watt white light LED bulb was used in a structure designed to avoid shadows and improve the contrast of the potatoes on the conveyor belt. This structure ensures uniform illumination, which facilitates image processing and analysis (shown in Fig. 4).

Fig. 4. Darkroom system.

The process starts when the potatoes dumped into the hopper begin to fall onto the conveyor belt by gravity. To linearize the flow of potatoes, ensuring that each potato passes individually through the visual inspection area before being sorted by the separation system, a 35° parallel belt system was designed. In the final section of the path, the parallel belts are aligned completely horizontal on the transverse axis of the structure. The total dimension of the parallel belts is 2 m up to the traction roller which is coupled to the geared motor in order to facilitate the separation of the potatoes by means of a flag type diverter. Once the product is on the belts, it enters the dark room with artificial lighting. The camera captures the information about the size of the potato by means of a continuous video, the algorithm makes a comparison of the acquired image with the desired measurements previously assigned that are stored in the interface. In this way the size of the potatoes can be inspected. Fig. 5 shows the simplified process in a flow chart of the algorithm.

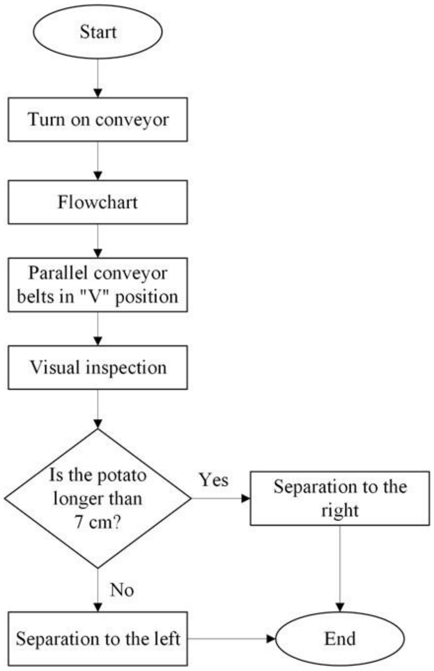

Fig. 5. Flow diagram of the potato inspection and grading process.

Image processing consists of transforming the image originally obtained into a grayscale image, as shown in Fig. 6. This is done to facilitate the color contrast between the potato and the conveyor belt. Since, the system identifies the shades of gray as analog values, on the monochromatic scale. The totally black color is assigned with a value of 0 and the white color with 255, with a spectrum of grays within it.

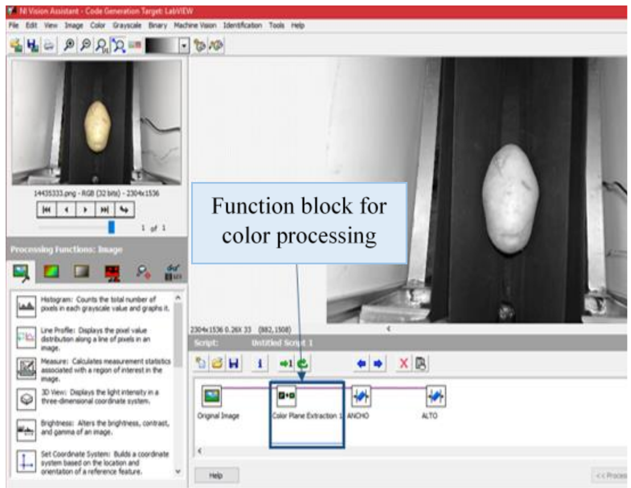

Fig. 6. Image processing with grayscale.

Once the original image has the color treatment, it goes to the next stage where the contours of the product are measured. This is done by scanning the pixels of the image, and when it detects a change in the color tone of the pixels, the system recognizes the outline of the product. Any value other than 0 is set to form the outline of the item under inspection. A horizontal and a vertical scan of the image is used to detect the longest size of the potato, since this is the operating condition for deciding its classification. Fig. 7 shows the detection of the width of the product.

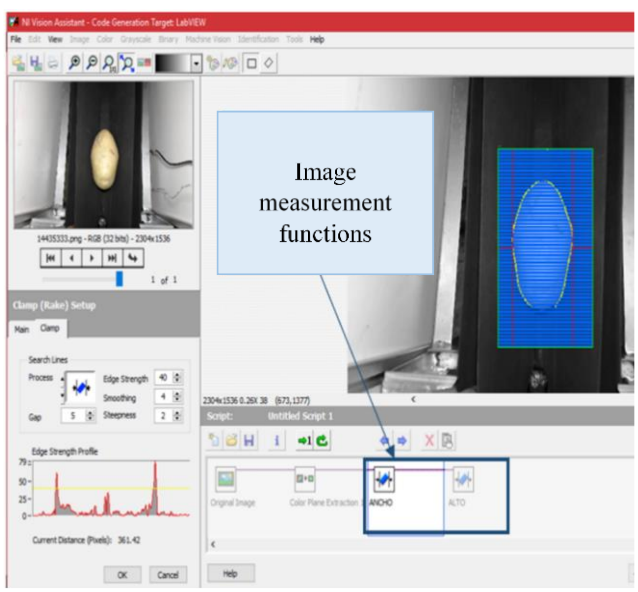

Fig. 7. Configuration of the function to measure the largest and smallest diameter of the potato.

After contour detection, logic functions are used to determine, from the measurements provided by the image processing, whether it is classified as a small or large size product.

The user interface was designed under the ISA 101 HMI standard and is the center of control, monitoring and processing of all signals and allows manipulation of system functions, such as stopping the conveyor belt, displaying the product image in real time and executing the decisions made by the classification software determined for each item under inspection. Fig. 8 shows an overview of the user interface workspace. In section 1, the image captured by the digital camera can be displayed. The indicators in section 2 show the activation status of the conveyor and dispenser. The interface has a panel for system control, for security reasons the start button was omitted so that the prototype can only be operated from the local station. It lights up in blue when a product larger than the requested size is detected and the other one lights up in violet when a smaller product is detected. Sections 3 and 4 represent the stop buttons available. The stop buttons act on the dispenser and the conveyor belt. Section 5 shows the size indicators.

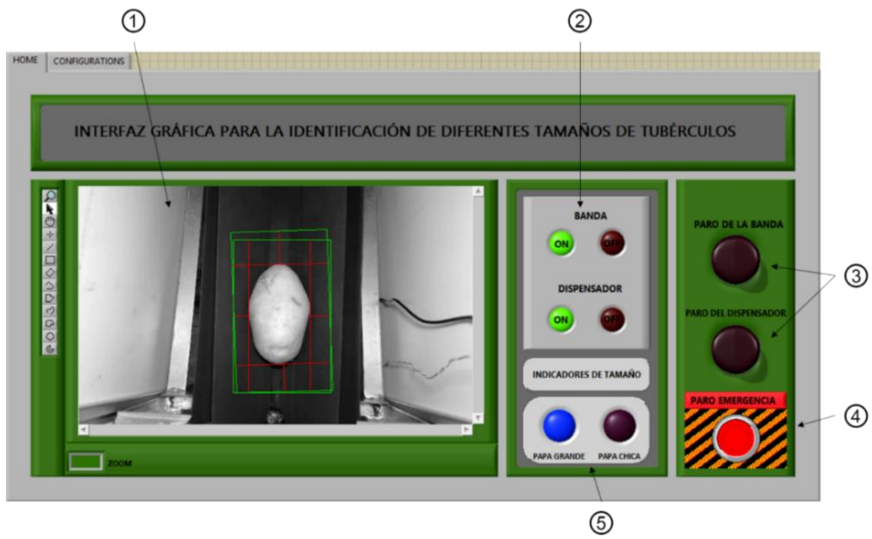

Fig. 8. HMI screen of the potato inspection and grading system.

The emergency stop button is located on the interface, when pressed, it should stop the entire system and in turn send a message with the legend “Emergency stop active”, for which, subsequently the option to reset is given, as demonstrated in Fig. 9.

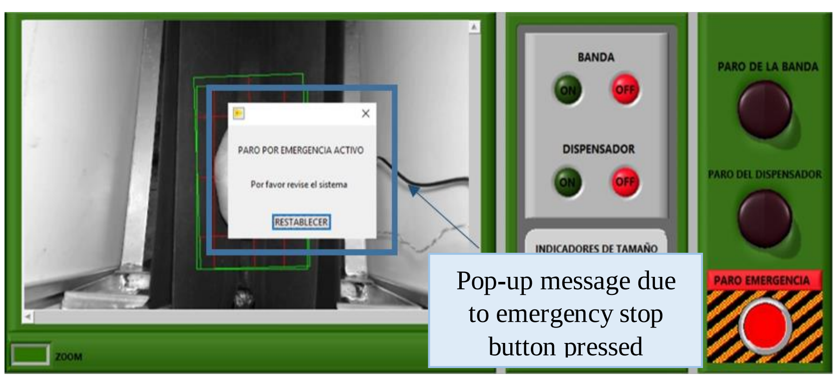

Fig. 9. HMI screen with emergency stop pop-up message.

Fig. 10 displays the operation of the product size indicators, and the classification assigned to them.

a)

b)

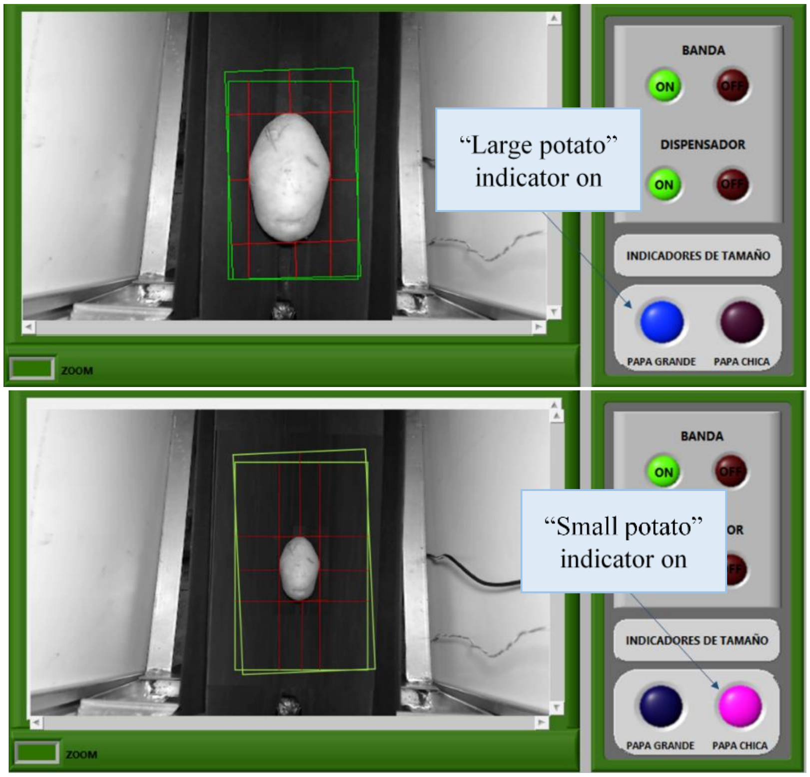

Fig. 10. a) Large potato indicator detected on the interface b) Small potato indicator detected on the interface.

In the selection tab in the size indicator menu of the HMI, the scale adjustment parameters can be configured. An image should be used as a reference and the scale should be chosen until the measurements of the object are visible in the selection box, see Fig. 11.

Fig. 11. Detection scale adjustment screen.

The scale was previously adjusted according to the height at which the camera is installed. Fig. 12 shows the operation of the separator device for product sorting by size.

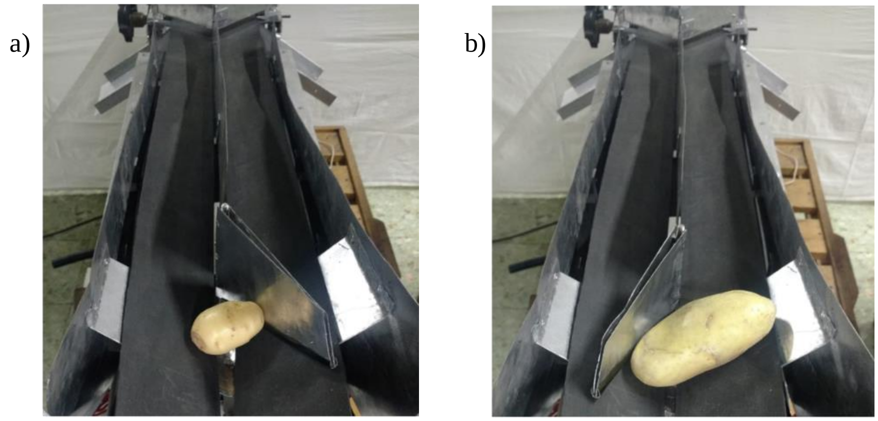

Fig. 12. a) Separation of small potato detected at interface, and b) Separation of large potato detected at the interface.

III. Results

One of the main indicators of success of the system is the increase in productivity, which is quantified from the volume of potatoes processed each time. A comparison between the manual process and the automated process is presented below (see Fig. 13):

Manual process: in one hour, the three operators sort about 90 kg of potatoes. In a 16-hour working day, 1,440 kg are processed. Over 7 days, up to 10,080 kg of potatoes can be processed.

Automated process: The automated system can sort up to 240 kg of potatoes per hour. In a 16-hour workday, the system sorts 3,840 kg, which represents a significant increase. In a week (7 days), the system can process 26,880 kg, increasing production capacity by 266.66% compared to the manual process.

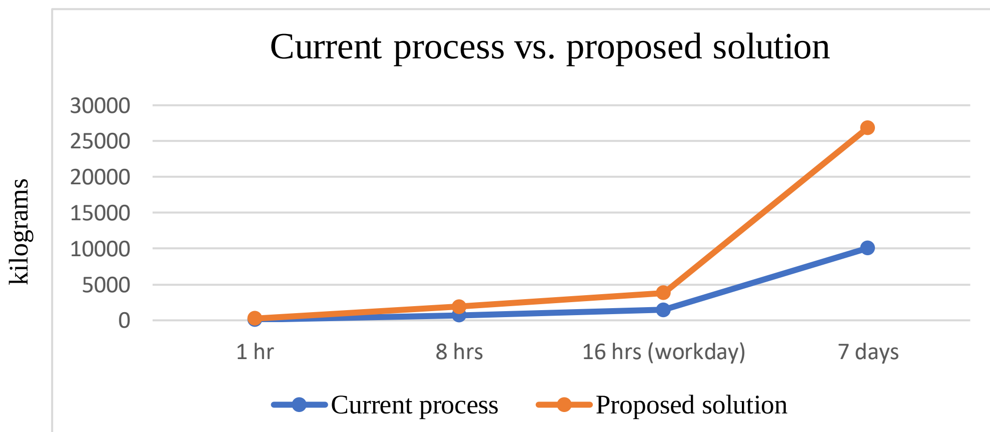

Fig. 13. Comparative plot between current process and semi-automated proposal.

This improvement not only reduces operating time, but also increases responsiveness to product demand, allowing the warehouse to process a larger volume of potatoes without increasing labor.

In the manual process, potato grading is subject to operator variability and fatigue, which generates an average error rate of 2.02% in size separation. This error is related to factors such as lack of visual accuracy, fatigue and subjectivity in sorting. With the automated system, the results were significantly better. The error rate of the automated system is only 0.44%, which implies a reduction of more than 75% in sorting errors. This accuracy is due to the use of an image processing algorithm that measures potato diameter with high consistency, eliminating the variability associated with the human factor.

The system allows the speed of the dispenser and conveyor belt to be controlled by the HMI, as illustrated in Fig 14. This adjustment ensures that the flow of potatoes is adequate and avoids pile up that could affect grading. It is recommended to operate the system at 80% of the gearmotor rated speed to optimize inspection time without compromising accuracy. This provides flexibility to adapt the system to different operating conditions.

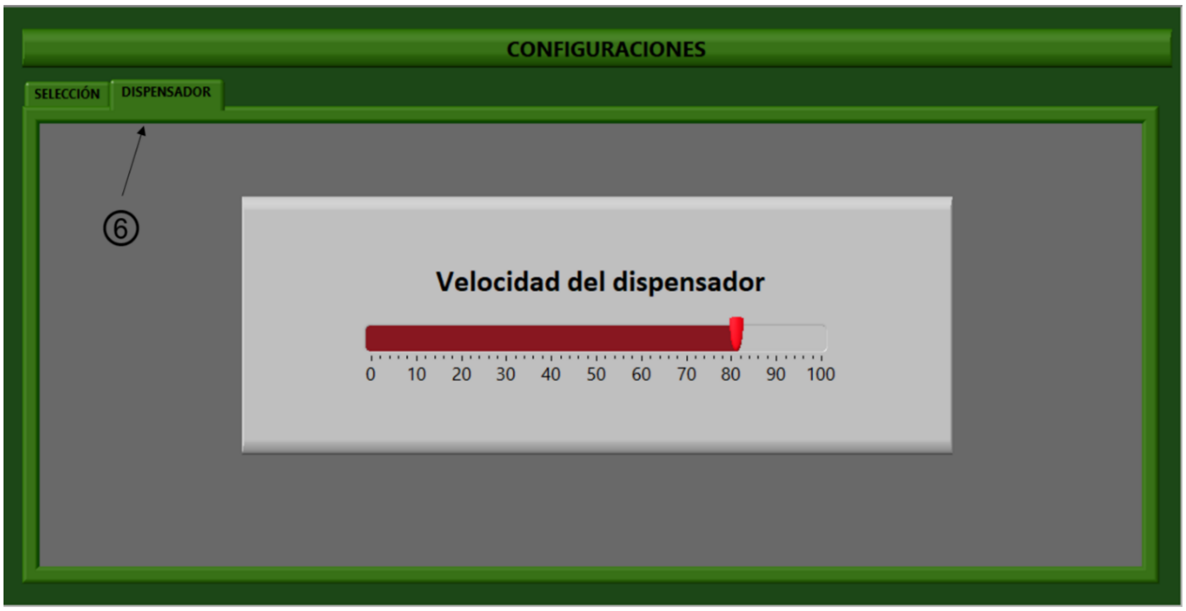

Fig. 14. HMI window for speed control of the dispenser.

IV. Limitations and Future Work

Automated tuber grading presents specific challenges as opposed to uniformly shaped fruits or vegetables. Tubers have irregular and asymmetrical contours that make accurate measurement difficult. Differences in size and shape can exceed the parameters handled by conventional systems. Moreover, inadequate illumination can generate shadows and saturated areas, compromising the accuracy of image processing.

An important line of future work is to extend the system's classification criteria to include weight, color and surface defects such as stains, cuts or deformities. For this purpose, convolutional neural networks (CNN) can be used to identify complex characteristics in agricultural products. In addition, the system could be adapted to other foods with different shapes and properties, such as carrots, onions or fruits, thus broadening its applicability in the food industry.

In terms of algorithms, the development of predictive models to optimize product flow on the conveyor could avoid congestion and maximize operational efficiency. At the mechanical level, the design of compact or modular components would help reduce manufacturing, transportation and maintenance costs. The system could also evolve to be scalable in industrial environments. This would involve processing larger volumes of products on extended production lines. In addition, integration with Industry 4.0 technologies, such as remote monitoring via the Internet of Things (IoT) and cloud analytics, would enable real-time monitoring of performance, automatic reporting and optimized decision making. The system could benefit from integration with data analytics techniques by studying patterns in production, such as variability in sizes or recurring defects, improving accuracy and adaptability in real time. This, combined with exploring its commercial viability as a modular package, would offer smallholder farmers the ability to customize the solution to their needs and budget, encouraging its adoption in a wider market.

V. Conclusions

The implementation of an automated potato grading system based on artificial vision has proven to be an efficient and accurate solution to optimize the sorting process of *Solanum tuberosum* in the food industry. From the results obtained, the proposed system was able to increase the grading capacity by 266.66% compared to the manual process. This has made it possible to process 26,880 kg of potatoes per week, which not only reduces operating times, but also increases the overall efficiency of the plant without the need to increase the number of workers. Due to the 266.66% increase in productivity of the grading system, an increase in the supply of yellow potatoes to the agricultural supplier is being considered, which represents a higher profit for the owners of the warehouse.

The cost-benefit analysis of the automated system highlights its positive impact in terms of productivity and error reduction. Initial costs include major components such as the camera, lighting system, motors and software development in LabVIEW™. These costs, although significant, are offset by the operational benefits generated. In addition, the 75% reduction in the error rate reduces losses associated with misclassifications. This increase in efficiency and accuracy generates significant savings in labor and operating time, resulting in a positive return on investment. This analysis reaffirms the economic viability of the system, positioning it as an accessible and cost-effective solution for the food industry.

The error rate was reduced from 2.02% in the manual process to 0.44% with the automated system. This demonstrates that the use of image processing algorithms and contour analysis is much more reliable than visual sorting by operators, eliminating subjectivity and human error due to fatigue.

The use of a high-resolution camera and a suitable lighting system allows detailed inspection of the potatoes, regardless of their irregular shape. This ensures that the system accurately detects the size of each potato, improving grading consistency.

The integration of a user interface allows real-time adjustments and provides effective safety controls. Operators can monitor and control the process without direct contact with the moving parts, reducing the risk of workplace accidents and improving working conditions. It is worth mentioning that the software does not allow the conveyor belt to be turned off without first deactivating the dispensing mechanism to prevent the conveyor belt from filling up with product when it is not working.

Although image acquisition systems can represent a high initial investment, the benefits in terms of efficiency, accuracy and reduced operating costs allow for a quick return on investment. Increased productivity, together with reduced errors and reduced labor requirements, generates a positive return for the plant.

The developed system is not only effective for potato grading but can also be adapted to other irregularly shaped products within the food industry. This opens opportunities for its implementation in other areas of the production chain, which could further increase its impact on the industry. The incorporation of machine vision technologies for food product sorting represents a step towards intelligent automation. This system proposes to improve productivity and reduce error margins, as well as optimize resource management and promote an efficient working environment.

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CRediT (*Contributor Roles Taxonomy*)

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