Design and Implementation of Automatic Palletizing System with Vision Based Algorithms for Quality Control

Diego Arce
Dept. of Engineering
Pontificia Universidad Católica del Perú
Lima, Perú
0000-0002-7350-1709

Gustavo Pérez-Zuñiga
Dept. of Engineering
Pontificia Universidad Católica del Perú
Lima, Perú
0000-0001-5946-1395

Edelfre Flores
Dept. of Engineering
Pontificia Universidad Católica del Perú
Lima, Perú
edelfre.flores@pucp.edu.pe

Francisco Cuellar
Dept. of Engineering
Pontificia Universidad Católica del Perú
Lima, Perú
0000-0002-6661-5118

Victor Jimenez
Calificaciones e Innovaciones en Ingeniería
Instituto Quimioterápico S.A.
Lima, Perú
0000-0002-1057-3617

***Abstract*—In recent years, the pharmaceutical industry has been implementing automatic systems in their manufacturing and packaging processes. This has led to reduced risks, increased productivity, lower costs, and improved competitiveness. The adoption of Industry 4.0 principles and technologies has played a key role in automating processes and optimizing results. Therefore, this paper presents the design, implementation, and preliminary validation of an automatic palletizing and quality control system implemented in the solid drug production line. The proposed system incorporates two main technologies: intelligent computer vision and collaborative robotics, which are complemented with industrial-grade equipment and instruments. The computer vision system performs quality control on pallet boxes by detecting defects, tears, stains, and taping faults on each side of the boxes, as well as recognizing the text characters of the labels for subsequent processing. Additionally, a weight-based quality control is implemented to ensure that all boxes contain the exact number of solid drugs. Through preliminary validation tests, the viability of using this automated mechatronic system for the handling and quality control of boxes was demonstrated. The handling process was carried out using a collaborative robot, or cobot, and it was determined that the robot can complete palletizing and quality control of a pallet of 21 boxes in a total of 11 minutes and 33 seconds. This innovative solution represents a successful application of Industry 4.0 principles and technologies in the pharmaceutical industry, enabling companies to further optimize their processes and remain competitive in the market.**

***Index Terms*—Automation; Palletizing; Quality Control; Computer Vision; Mechatronics.**

I. Introduction

The pharmaceutical industry operates in an increasingly complex, dynamic, and competitive environment, which requires innovation in information technologies, automation of manual methods. Industry 4.0 principles and technologies can enable pharmaceutical companies to reduce the risks associated with the growing globalization of markets and improve a series of changes in the business economic scenario. Pharmaceutical companies in Peru maintain their presence in the national market; but considering that it has involved a great effort as a local industry, it is that they have been forced to carry out cost reduction programs, innovations and improvement of their processes. Some of the processes in which production indicators can be improved through the implementation of automated systems is the palletizing and quality control stage.

The palletizing process usually includes repetitive actions, usually carried out by operators. For this reason, especially in palletizing applications, ergonomics is a factor that can be regulated and must be taken into account [1]. For cleanliness reasons, the food, pharmaceutical and semiconductor industries use palletizing robots [1]–[4]. Another reason is to avoid monotonous and mentally stressful jobs, to ensure quality control [5]. In applications and uses of collaborative robots (COBOTS) we find the literature presented in [6].

Regarding quality control, there are investigations where computer vision techniques are applied for the detection of edge and surface defects of boxes and detection of text printing defects. In [7], developed a computer vision algorithm that is capable of obtaining the volume of parcel boxes of different dimensions for an automatic sorting line. In [8] a method is proposed to estimate the position of a cardboard box based on computer vision without the need to place markers. In [10] the recognition of the expiration dates of cardboard packages of medicine packages from images is proposed. In [11] is developed a method that allows automating the verification process and reducing labeling errors in food packaging. In [12] is proposed the use of neural networks to identify expiration dates with adequate results using images with different contrasts.

The contribution of this work is to present the design, implementation and preliminary validation of an automatic palletizing and quality control system implemented in the production line of a pharmaceutical company in Peru. In particular, the paper highlights the quality control system using artificial vision to determine the acceptability of final products in a production line. The system verifies two key aspects: 1) the detection of defects on the edges and surfaces of boxes and the printing of text; and 2) the weight of the boxes, which must fall within a predetermined range to ensure that all boxes contain full blister packs. This quality control system is seamlessly integrated into an automatic palletizing system that includes handling, weighing, and labeling of the final product. The implementation of this automated system was preliminarily validated, and it resulted in significant time savings compared to the manual process.

This article is organized as follows: Section II presents a brief description of the case study where the automated system will be applied and presents the design of the automatic palletizing system and the design of the quality control system; Section III presents some important preliminary activities for the system, Section IV presents the implementation of the vision system for quality control. Finally, Section V presents the conclusions of this study and mentions future work based on this research.

II. System Design

A. Case of study

The *Instituto Quimioterapico S.A.* has a automated equipment for the blistering, boxing and cartoning processes. The new equipment is the UHLMANN BEC 500, which has the capacity to produce 500 blisters/minute. For reasons of performance and consideration for the operators in the palletizing activity, it is necessary to replace them with a system with intelligent robots that interact with humans, integrated into an intelligent vision system with image processing with connectivity to a PLC and intelligent sensing. This will allow to have a quality and safety control with compliance with the standards. In addition, it must have a quality control system before palletizing, in order to guarantee that the boxes that come out of the automatic machine do not have faults and weight within an predetermine range.

B. Mechatronic Design of Automatic Palletizing System

The designed mechatronic system is composed of a palletizing subsystem, a weighing subsystem, a computer vision subsystem for quality control and a centralized processing subsystem (as shown in Figure 1). The palletizing subsystem consists of a collaborative robot (Cobot), its controller and a manipulator (Gripper). The weighing subsystem is composed of a high-precision scale and a lifting and lowering mechanism activated by a pneumatic actuator. The computer vision subsubsystem is composed of an RGB camera, two LED lamps and a specialized computer for image processing. Finally, the centralized processing subsystem consists of a programmable logic computer (PLC) which has a SCADA system, through which all system peripherals (sensors and actuators) are monitored and controlled.

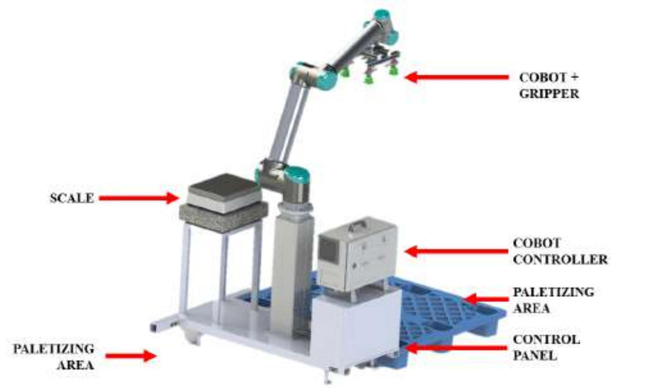

Fig. 1. 3D model design of automatic mechatronic palletizing system.

The cobot manipulator used is a gripper with four pneumatic suction cups to be able to hold boxes of up to 12 kg. For the activation of the suction cups was neccesary to implement a pneumatic configuration such as the one shown in Figure 2. This diagram represents all the components necessary to activate the suction of the boxes through an electrovalve that will be commanded by the controller of the cobot.

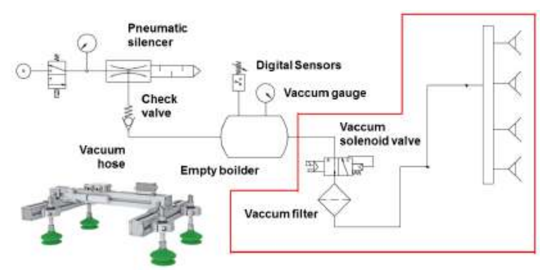

Fig. 2. Pneumatic diagram for Cobot gripper.

C. Computer vision subsystem for quality control

This section details the installation of the components that make up the vision system that will be used for quality control of boxes and labels. The vision system is made up of one (01) computer, one (01) camera with lens, two (02) LED lamps and three (03) power supplies. Figure 3 shows the vision system connection diagram and Figure 4 shows the lighting system connection diagram.

For the assembly of the components of the quality control system, it is necessary to have some mechanical supports for the assembly of the camera and the luminaries. These supports were designed so that the height and rotation of the components can be adjusted. From this, the design of a mobile support adjustable in height and rotation of the component was developed (see Figure 5.a. This same design can be used both for the assembly of the cameras and the luminaries only by changing an adapter, managing to mount the camera (see Figure 5.b) and the luminaries (see Figure 5.c).

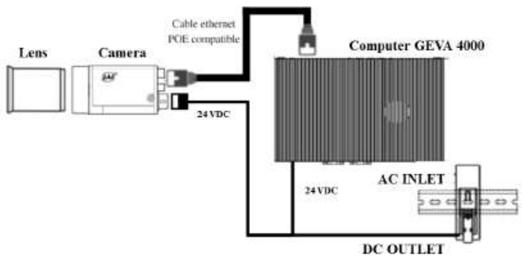

Fig. 3. Connection diagram of vision system.

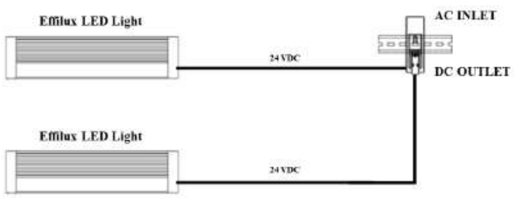

Fig. 4. Connection diagram of lightning system.

D. Weighing scale subsystem for quality control of weight

After the process of blisting, cartoning and cartoning the product in its respective packaging box is performed, a final verification of the weight of the box is made at the end of the line, in order to reduce the risk due to the probability of failure in the UHLMANN BEC 500 inspection system.

This intelligent quality control palletizing of the weight of the packing boxes is performed through the following steps:

- 1 gram sensitivity scale is used.
- 10 samples of empty box, inserts, cases and blister with products are taken.
- The population mean is estimated with the t samples and the standard deviation

Then, values of its initially obtained mean and standard deviation are the values with which training is performed to obtain the true mean and standard deviation of the population of a given product.

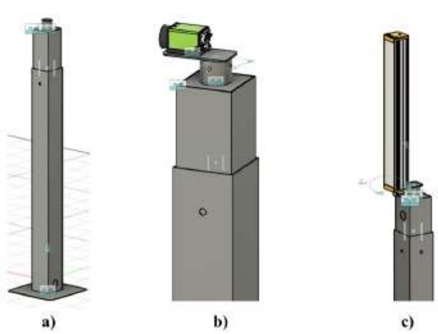

Fig. 5. Adaptable movable bracket for vision system: a) Bracket Design; b) Camera bracket; and c) LED light bracket.

Fig. 6. Samples of inserts, cases and blister with products for quality control of weight training.

E. Full system integration

The system implemented is presented in Figure 7. This figure shows the end of the production line for boxes with solid drug blister packs. At the end of the line, the previously described mechatronic system is positioned. The Universal Robot UR10 cobot is shown with the suction cup manipulator. It has a weighing scale and a pneumatic system for raising and lowering the boxes. The vision system is composed of a Geva 4000 computer, a GOX-5103M-PGE camera and an SDR-75-24 source. The lighting system has two Effilux LED lamps and two SDR-75-24 sources. The main controller is a PLC-S7 1200 interconnected with the other peripherals and controllers through profinet and digital I/O. In addition, there are two palletizing areas on the sides, which have distance sensors to detect the presence of the pallets before sorting.

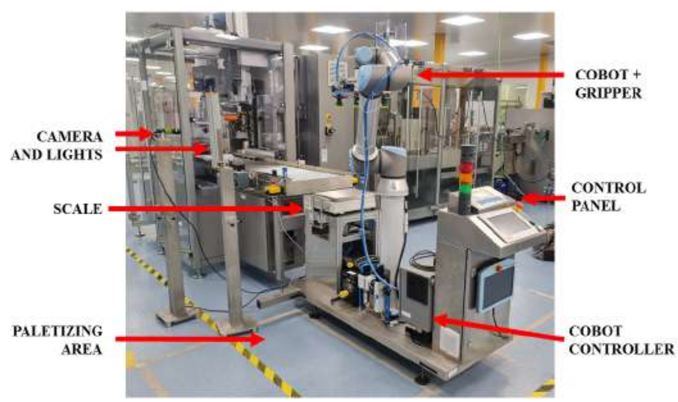

Fig. 7. Automatic mechatronic palletizing system implemented.

The quality control process proposed with this automatic system if presented in Figure 8, which consiste in 4 stages. The fist stage is quality control by visual inspection, by using the computer vision subsystem. This stage of quality control focus on determine if the box have any kind of surface defects and if the box shape if correct. The second stage focus on quality control by weight, which uses the high precision scale. In this stage the box weight is measure and compared to a predetermine acceptable range in order to assure the all the blisters contain products. The third stage consists in printing

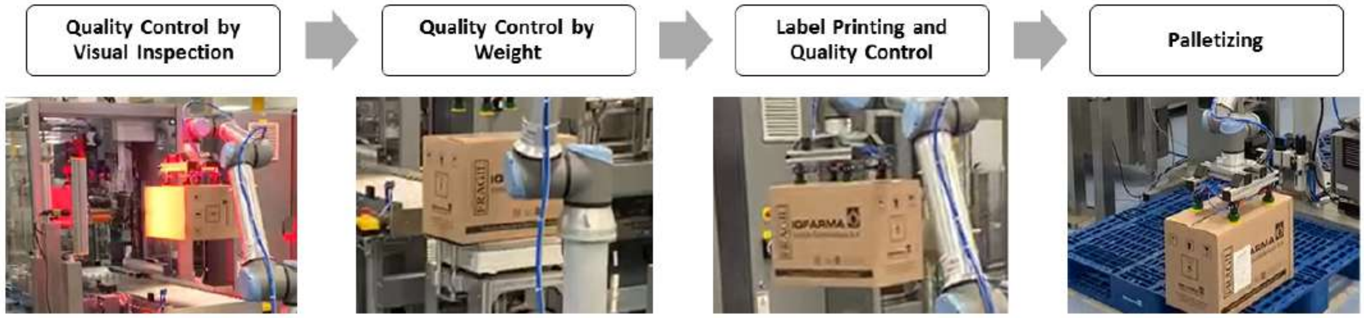

Fig. 8. Quality Control Process of Automatic Palletizing System.

the label information and then verifying if the information printed is correct, for which is used the computer vision techniques. The last stage involves the palletizing process based on the previous stages.

III. Preliminary activities

A. *Automatic Paletizing Process Validations*

To validate the automatic palletizing process executed by the robotic system, it is necessary to define the movement sequences that must be executed. Two movement sequences were worked on: movement for quality control and movement for palletizing. Based on both defined sequences, the real movements are programmed and executed with the robot in order to verify the feasibility of the movements and measure the execution times of each sequence.

The movement sequence for quality control is conformed of the actions detailed in Figure 9. This sequence is composed of seven (07) actions, which begin with the collection of the box, positioning in front of the camera to start the inspection and the rotation of the box in order that the four (04) side faces can be inspected.

Fig. 9. Sequence for quality control manipulation with Cobot.

The movement sequence for palletizing is conformed of the actions detailed in Figure 10. This sequence is composed of five (05) actions, which continue after the quality control sequence and continue with the necessary movements to reach the palletizing areas according to the acceptance or rejection of the box. Safety positions are used at high points in the palletizing areas so that the safe movement of the robot can be carried out.

From the tests carried out with the movement sequences described above, the movement was executed at two speeds of the robot, at medium speed (50%) and at maximum speed

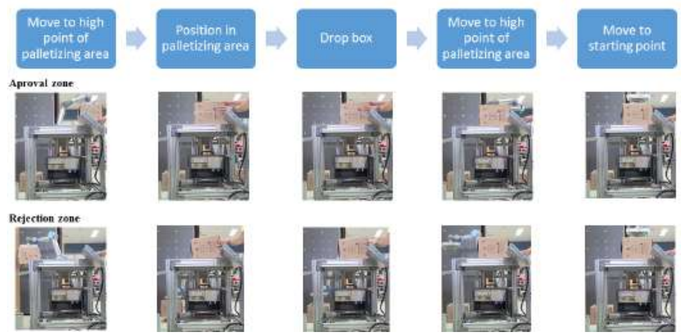

Fig. 10. Sequence for palletizing boxes with Cobot.

(100%). From these tests it was possible to measure the execution times of the quality control and palletizing sequences. The determined times are indicated in Table 1.

TABLE I
Determination of times of movement sequences

Sequence	Sequence time	
	Speed at 50%	***Speed at 100%***
Quality control	30 s	19 s
Palletizing of 1 box (acceptance zone)	28 s	14 s
Palletizing of 1 box (rejection zone)	28 s	14 s

From the time information obtained, it is possible to determine the maximum time for assembling a pallet. For this, the following equation is used:

$$tT = ((cN * cC) * (tCC + tP)) * (1 + err) \tag{1}$$

where tT: total process time cN: number of pallet levels cC: number of boxes per level tQC: quality control time tP: palletizing time err: percentage probability of failure detection

In this way, for the tests that are being carried out considering 100% speed, pallets of 7 boxes per level (cN) and 3 levels (cC) would have a total time of 693 seconds (11 minutes and 33 seconds) considering 0% probability of errors.

B. Image Preprocessing

This subsection presents the different computer vision algorithms applied to the original images in order to enhance the defects on the boxes for the quality control stage. The algorithms tested were Thershold, Prewitt operator and Canny operator. This three algorithms can be implements with the specialized computer vision software Sherlock software which in installed in the Geva 4000 computer.

Threshold

Initially a threshold is defined, usually according to a histogram, where tones below this threshold turn white and tones above the threshold turn black. This facilitates the execution of some algorithms by having a cleaner image. In Figure 11 it is shown the execution of this method.

Fig. 11. Threshold applied to the boxes.

Sobel operator

This pre-processing makes it possible to detect the intensity changes that appear in the images under study, so that the image gradients are found and the maximum points can be detected, being able to use this information to detect contours.

Taking into account the type of region of interest used in this project, the application of Sobel-type pre-processing was determined by applying a convolution of a 3x3 matrix with the original image to better detect the horizontal and vertical edges depending on of the matrix configuration.

Prewitt operator

The application of the Prewitt operator is similar to the Sobel operator but the values in the 3x3 matrix are changed to have another result, in which a high gray scale value would indicate a possible edge.

Figure 12 a) shows the image of an original box without processing. Then, figure 12 b) shows the convolutions applied and the first results obtained by applying the Sobel and Prewitt operator using these convolutions.

Canny operator

The Canny operator, also known as optimal edge detector, has a low error rate and is also robust. The Canny operator first converts the image to grayscale and performs noise reduction by applying the Gaussian filter, then suppression to identify edge pixels, and finally a threshold with hysteresis to remove weak edges. In figure 13 it is shown the effects of the Canny operator.

Through multiple tests with the Sherlock software, it was determined that applying a Gaussian filter after the Canny operator gives better results for edge detection. Figure 13 b) and

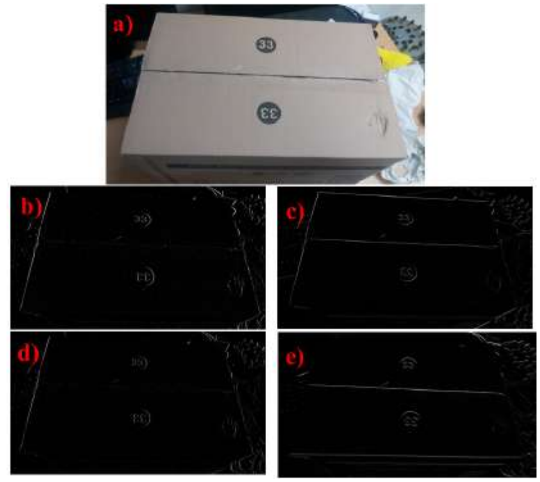

Fig. 12. Results of the Sobel operator: a) Box image without processing; b) Result of vertical Sobel operator; c) Result of horizontal Sobel operator; d) Result of vertical Prewitt operator; e) Result of horizontal Prewitt operator.

c) show a comparison between the two results, highlighting a much more precise delineation of the edges in the second case.

Fig. 13. Results of the Sobel operator: a) Box image without processing; b) Canny Operator; c) Canny operator plus Gaussian filter.

IV. Implementation of the Vision System for Quality Control

In this section, the algorithms implemented using the Sherlock development software for the quality control of the boxes are presented, taking into account the recognition of anomalies in labels, edges, tapes and stains of boxes at the end of a production line. Preliminary results obtained with test images carried out with the project camera and with external cameras are presented.

A. Geometric search algorithm

The "geometric search" algorithm aims to recognize patterns in images, this through a goal set by the programmer. Once the objective is set, the algorithm is executed on images and returns a variable for each one with the similarity of the objective, in addition there is a threshold with the function of detecting the object correctly, with values lower than the threshold being incorrect and values greater to the correct threshold.

The algorithm has 3 stages:

- Train a suitable sample of the features.
- Define a search area
- Acquisition of new images, location of features to determine their location and similarity value.

Initially, the “geometric search” algorithm was applied to some images with the box labels, the results are presented in figure 14.

When using the algorithm, images were used using external cameras and a threshold was applied previously to binarize the image. When the algorithm detects a similarity greater than the threshold, it generates a copy of the target in green.

This algorithm can detect the similarity of the target regardless of the position, which will serve to align the other algorithms, being able to determine the appropriate position. As an example, figure 14 c) shows the algorithm detection with rotated position.

Fig. 14. Results of the Sobel operator: a) Application of the ”geometric search” algorithm; b) Similarity values and object detection; c) Object detection in rotated image.

Subsequently, tests of the algorithm were carried out with images using the project’s camera, in figure 15 the results can be seen, it is identified that the considered text patterns can be properly recognized.

Fig. 15. Application of the algorithm ”geometric search”.

B. Gray scale OCR algorithm

The ’Gray scale OCR’ algorithm is used to detect characters in previously trained images. This training makes detection more accurate if you have a larger amount of data. Once trained, the algorithm is applied, obtaining results depending on the amount of training. In figure 16 it can be seen that for the detection of the word ’CÁPSULAS’ and ’ALIPIDEM’, also on the right side of the image there are the values recognized by the algorithm.

Then applying the tuned algorithm for the entire label allows the detection of all the necessary words as shown in figure 17.

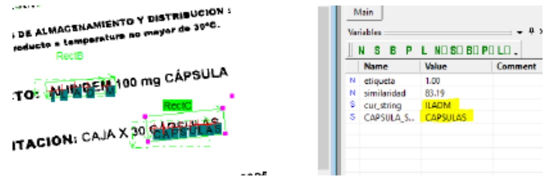

Fig. 16. Character recognition results.

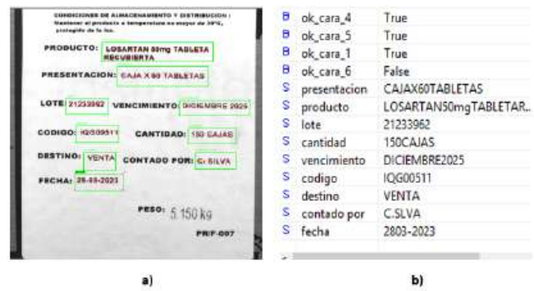

Fig. 17. Recognition of characters on labels: a) Application of the ”gray scale OCR” algorithm; b) Detection obtained in the Sherlock software.

C. Connectivity Binary Algorithm

The ‘Connectivity Binary’ algorithm can be used prior to applying a ‘threshold’ to the image, since the algorithm detects the white or black conjoined regions. This detection allows us to recognize ’disturbances’ and thus detect some type of deformation or stain in a box. Results of perturbations in boxes and the application of the ”Connectivity Binary” algorithm are presented in figure 18.

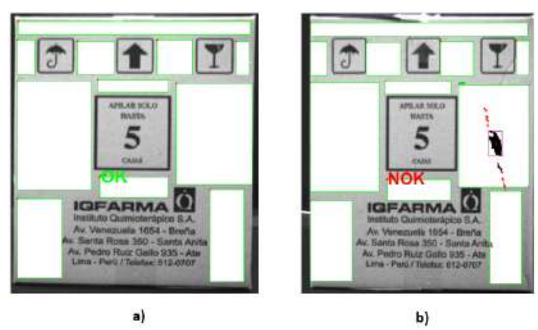

Fig. 18. Results of the disturbances in boxes: a) Application of the ”Connectivity Binary” algorithm in a nominal box; b) Application of the “Connectivity Binary” algorithm in a failed box.

D. Comparative analysis of lighting color

From this analysis the following findings are presented:

- Tests were made on how the tape is displayed against different colored backgrounds.
- It was evidenced that the mustard color has a better gradient in the gray scale based on the comparative table made.
- Final recommendations were provided in case you want to use that lighting color.

Tests were made on how the tape and labels are displayed under different plant conditions. Plant conditions only allow the direct illumination method and this method was used with the light tests. It was evidenced that the tape with the proposed logo and without lighting is the one that allows the best visualization of the taped region. It was evidenced that the label without lighting improves readability and also generates better consistency in image capture. This is evident in figure 19.

Fig. 19. Label image: a) without illumination; b) with direct lighting; c) with indirect lighting.

V. Conclusions and Future Work

An automatic quality control and palletizing system was implemented to be installed in a solid drug production line at the output of the Uhlmann BEC500 automatic line. This system is composed of the components of the vision system (computer, lamps and camera); a prototype of a suction cup manipulator; a weight-based quality control and a UR10 cobot. Validation tests were performed to determine the feasibility of the system. The tests were focused on the execution of the box handling and palletizing process, through which it seeks to demonstrate the feasibility of the mechanical-electrical system. From this first test, the measurement of the execution time and effectiveness parameters (depending on the speed of the robot) was defined for the quality control sequence and for the palletizing sequence. It was determined that the robot can carry out the palletizing (pellets of twenty-one (21) boxes, considering seven (07) per level, with quality control in a total of 11 minutes and 33 seconds.

A vision system has been developed for quality control in pallet boxes, capable of detecting anomalies in edges, tapes, and stains of boxes at the end of a production line, as well as recognizing text characters on labels for subsequent processing. The vision system's algorithms, including Geometric Search, Connectivity binary, Gray Scale OCR, and Rake, have demonstrated the ability to accurately detect specified failures. Experimental validation tests conducted in a pharmaceutical plant confirmed the vision system's effectiveness for quality control.

Future work includes testing the efficiency of the implemented system during line production operations. Key Performance Indicators (KPIs) will be defined to measure the system's level of performance and optimization compared to the previous manual process. In terms of quality control algorithms, machine learning algorithms will be implemented and tested to improve the quality control process. These algorithms will be compared to existing ones, and their performance evaluated.

Acknowledgment

The authors would like to thank the National Program for Technological Development and Innovation ProInnóvate (PROINNOVATE) through INNOVATE PERU funds (PIEC1-6-P-183-164-20) and the company Instituto Quimioterapico S.A. (IQFARMA) for providing the funds and means to carry out this work.

References

[1] A. Kahn: The Encyclopedia of Work-related Illnesses, Injuries, and Health Issues (Facts On File, New York 2004)

[2] M. Wilson: Developments in robot applications for food manufacturing, Ind. Robot Int. J. 37(6), 498– 502 (2010)

[3] R. Moreno Masey, J. Gray, T. Dodd, D. Caldwell: Guidelines for the design of low-cost robots for the food industry, Ind. Robot Int. J. 37(6), 509–517 (2010)

[4] K. Mathia: Principles and Applications in Cleanroom Automation (Cambridge Univ. Press, Cambridge 2010)

[5] D. Rossi, E. Bertolini, M. Fenaroli, F. Marciano, M. Alberti: A multi-criteria ergonomic and performance methodology for evaluating alternatives in "manuable" material handling, Int. J. Ind. Ergon. 43(4), 314–327 (2013)

[6] S. Robla-Gomez, V. Becerra. "Working Together: A review on Safe Human-Robot Collaboration in Industrial Environments", IEEE Access (Vol. 5), pp. 26754-26773, 2017, ISSN 2169-3536.

[7] Yunardi, R. T. (2015, October). Contour-based object detection in Automatic Sorting System for a Parcel Boxes. In 2015 International Conference on Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation (ICAMIMIA) (pp. 38-41). IEEE.

[8] Medjram, S., Brethe, J. F., & Benali, K. (2020). Markerless Vision-Based One Cardboard Box Grasping using Dual Arm Robot. Multimedia Tools and Applications, 79, 22617-22633.

[9] Luo, Y., Chen, Y. (2021). FPGA-Based Acceleration on Additive Manufacturing Defects Inspection. Sensors, 21(6), 2123.

[10] Koponen, J., Haataja, K., & Toivanen, P. (2021). Text Recognition of Cardboard Pharmaceutical Packages by Utilizing Machine Vision. Electronic Imaging, 2021(10), 235-1.

[11] Thota, M., Kollias, S., Swainson, M., & Leontidis, G. (2020). Multi-source domain adaptation for quality control in retail food packaging. Computers in Industry, 123, 103293.

[12] Ribeiro, F. D. S., Gong, L., Calivá, F., Swainson, M., Gudmundsson, K., Yu, M., ... & Kollias, S. (2018, October). An end-to-end deep neural architecture for optical character verification and recognition in retail food packaging. In 2018 25th IEEE International Conference on Image Processing (ICIP) (pp. 2376-2380). IEEE.