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A CASE-STUDY VISION

Automated technologies implemented in the FMS HAS200

Tecnologías automatizadas implementadas en la FMS HAS200

Luini Leonardo Hurtado-Cortés [1], *John Alejandro Forero-Casallas* [2], *Víctor Elberto Ruiz-Rosas* [3]

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ABSTRACT

This paper presents the automation implemented through a series of projects oriented towards the continuous improvement and development of the didactic systems present in HAS200 flexible manufacturing cells of the Facultad Tecnológica of the Universidad Distrital Francisco José de Caldas. Through these projects, it has been possible to implement a series of automated improvements such as (i) a virtual environment of the flexible manufacturing cell, geometrically modeled for remote simulation of the didactic processes; (ii) a new automated station for recycling pellets that is integrated with the other stations to classify the raw material in three separate colors; (iii) a new user-machine interface for a Melfa Mitsubishi RV-M1 manipulator arm, which allows the recycling station to be integrated with the rest of the flexible manufacturing cell; iv) an automated gripper design for handling and subsequent opening of containers within the cell; v) an artificial vision system implemented to alternate autonomous transport of product between stations using unmanned ground vehicles; vi) a virtual course for the management and operation of the flexible manufacturing cell. The automation strategies proposed in the HAS200 can be extrapolated to real production environments under the same automation concepts, which makes each result obtained doubly beneficial.

RESUMEN

En este artículo se presenta la automatización implementada a través de una serie de proyectos orientados hacia el continuo mejoramiento y desarrollo de los sistemas didácticos presentes en celdas de manufactura flexibles HAS200 de la Facultad Tecnológica de la Universidad Distrital Francisco José de Caldas. Por medio de dichos proyectos se ha logrado implementar una serie de mejoras automatizadas como por ejemplo: i) un entorno virtual de la celda de manufactura flexible, modelado geométricamente para la simulación remota de los procesos didácticos; ii) una novedosa estación automatizada para el reciclaje de pellets que se integra con las demás estaciones para clasificar la materia prima en tres colores separados; iii) una nueva interfaz de usuario-máquina para un brazo manipulador Melfa Mitsubishi RV-M1, que permite integrar la estación de reciclaje con el resto de la celda de manufactura flexible; iv) un diseño de gripper automatizado, para la manipulación y posterior apertura de recipientes dentro de la celda; v) un sistema de visión artificial implementado al transporte autónomo alterno de producto entre estaciones mediante vehículos terrestres no tripulados; vi) un curso virtual para el manejo y operación de la celda de manufactura flexible. La automatización propuesta en la HAS200 puede ser extrapolable hacia entornos productivos reales bajo los mismos conceptos de automatización, lo cual hace que cada resultado obtenido sea doblemente beneficioso.

1 MSc. in Engineering - Automation, PhD. in Engineering - Automation. Current position: Titular Professor at Universidad Distrital Francisco José de Caldas, Bogotá, Colombia. E-mail: llhurtadoc@udistrital.edu.co

2 MSc. in Engineering - Automation. Current position: Assistant Professor at Universidad Distrital Francisco José de Caldas, Bogotá, Colombia. E-mail: jaforeroc@udistrital.edu.co

3 BSc. in Mechanical engineering. MSc. in Mechanical engineering. Current position: Assistant Professor at Universidad Distrital Francisco José de Caldas, Bogotá, Colombia. E-mail: veruizr@udistrital.edu.co

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1. Introduction

Currently, the Universidad Distrital Francisco José de Caldas has a manufacturing cell to perform technological practices of automation, this manufacturing cell is called HAS200, is a modular system of eight workstations and has a serial production process, which implies that each process is performed in one after the other, the stations present in this manufacturing cell are: Multicolor can feeder, production, measuring, cap placement, warehouse, palletizing, raw material storage, and recycling station. As it is a serial manufacturing cell, there may be limitations in terms of simulation times when it is necessary to restart the container production system. The raw material comes out mixed between the different colors of didactic simulation; the mixed colored beads must be separated and stored again by the machine operator, an activity that goes against the original idea of automation of production processes related to flexible manufacturing systems. A series of projects related to state-of-the-art technologies have been developed to complete the absolute cycle of automation within the flexible manufacturing system.

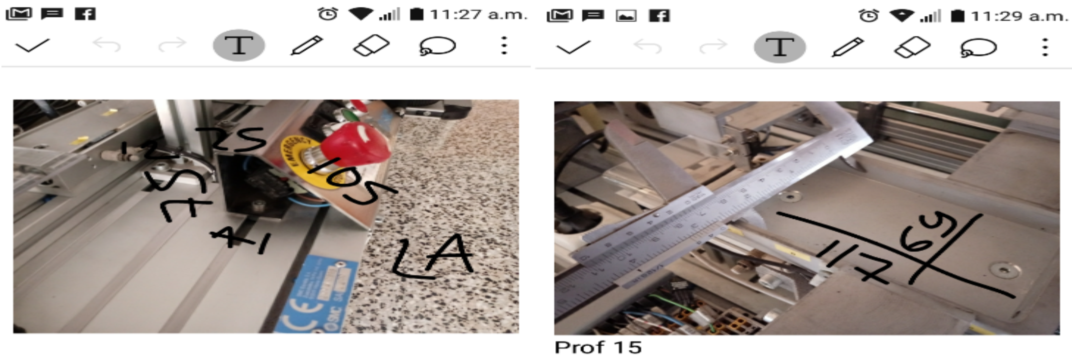
2. Virtual Environment HAS200

The project developed makes available the manufacturing cell located in the Faculty of Technology in a virtual environment, where each of the workstations with their respective subassemblies are identified, offering teachers and students a tool for the development of the class taught, additionally with the modeling of the station is delivered to the faculty a basis for the development of projects related to manufacturing cells. A thorough search for information about the cell, its elements and components, their operation, and the way they interact was carried out to obtain the assembly of the rotating system composed of five parts, a base or body, a bearing, an axis, a cover, and the screws to contain the elements. The next step was the modeling of the elements employing a computer-aided design tool CAD (Computer - Aided Design), in which the modeling of each one of the subassemblies that compose each station was done first and then the assembly of all of them was done to conform the manufacturing cell.

Figure 1. HAS200 Flexible Manufacturing Cell.

Source: own.

Figure 2. QuickMemo+® application for annotation of measurements on images.



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Finally, Siemens® NX 8.5 software was implemented to simulate the movements of station 1, feeding the base or body, where each of the steps that are carried out within the process in the operation of the manufacturing cell can be distinguished, which corresponds to the times and sequence in which the real cell works in the laboratory of the University. With the development of the project, the modeling of the cell and each of its stations in a virtual environment was achieved, which can be consulted for identification of its components by students and teachers who offer lectures with the cell as a working tool, additionally, an information base is available for the development of future projects related to the manufacturing cell.

2.1. Development of drawings

It is the fundamental basis of this project because here each of the components was characterized in terms of sizing, positioning, and structuring of the stations of the manufacturing cell and turn the verification and correction of components acquired in the network.

The QuickMemo+® mobile application was used to add the measurements taken to images of the manufacturing cell.

2.2. Search for standardized graphic elements

This part is of vital importance for the assembly of the stations during the modeling, the greatest precision was sought when establishing the different parts and components that are used for the union of the parts of the manufacturing cell and that are known to be found in databases of CAD programs in the different consultation networks on the web.

Figure 3. Aluminum profiles download page.

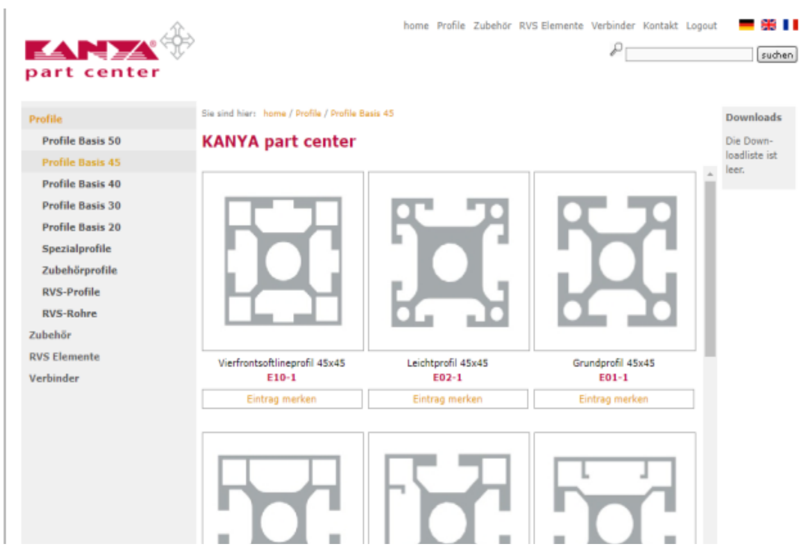

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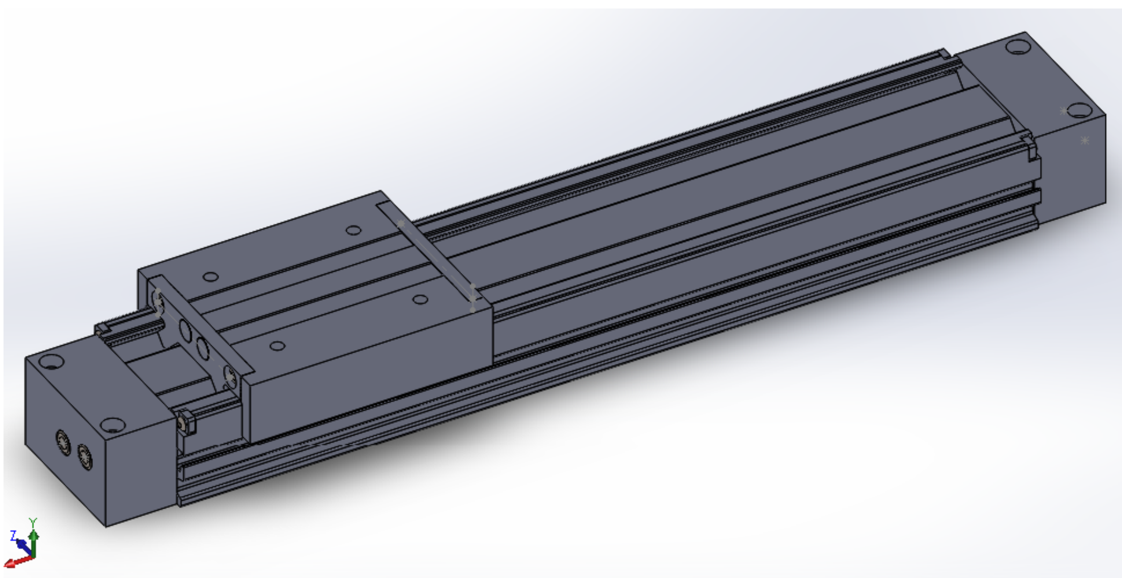
Figure 4. SMC® components download the home page.

Source: own.

Figure 5. MY1C25G - 200 - actuator downloaded for Solid Works®.



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2.3. Modeling of sub-assemblies of each station

It deals with the verification of the joining of parts and surfaces for the transmission of movements, analysis of stops, and interferences of movements between parts, and forces between them for the assembly of components that perform specific tasks. Each of the stations was developed virtually separately and the virtual model of stations 1, 2, and 3 are presented in Figure 6 as an example.

Figure 6. 3D Solid Works® modeling of stations 1, 2, and 3 (color bead dispenser) HAS200® manufacturing cell.

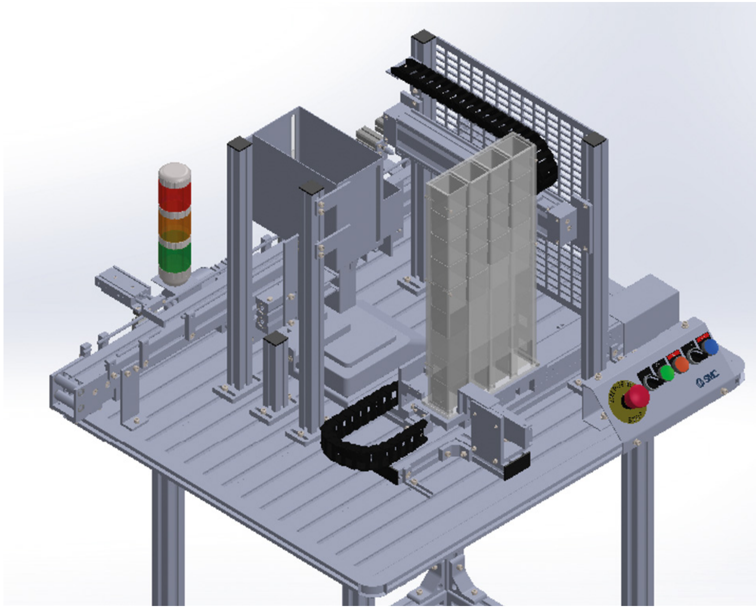

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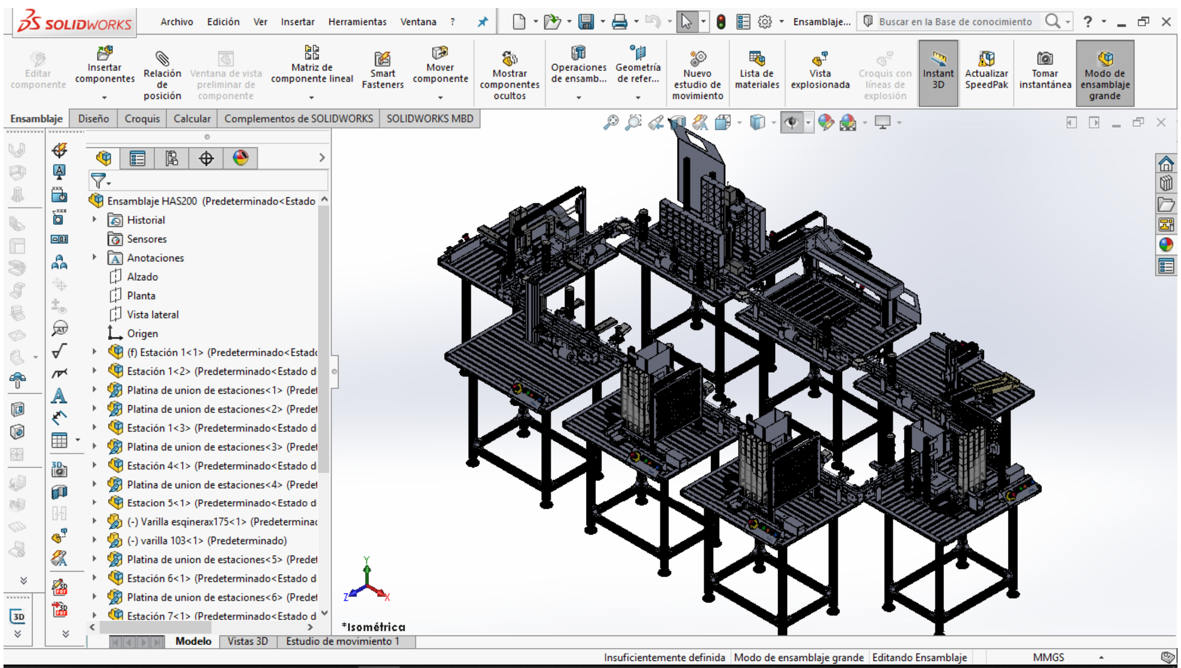
Figure 7. HAS200 manufacturing cell modeling in Solid Works® environment.



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2.4. Manufacturing cell assembly

Alignment of the assemblies of every one of the workstations, in the case of the FMS200 manufacturing cell, using linear conveyor belts for each station that are intercommunicated in a "U" shape for the entire cell, verifying the entry and exit of the product in each of the stations seen as a system.

Figure 8. HAS-200 manufacturing cell model rendered with Solid Works® software.

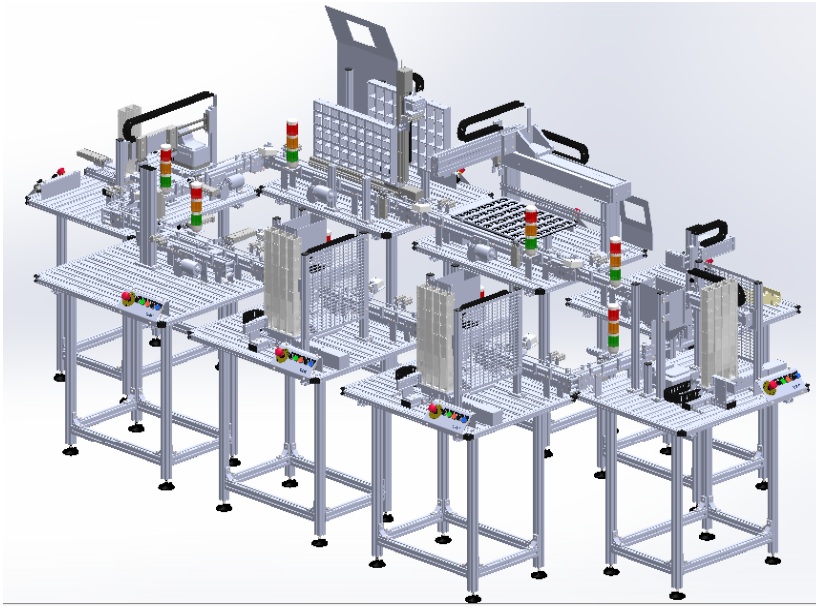

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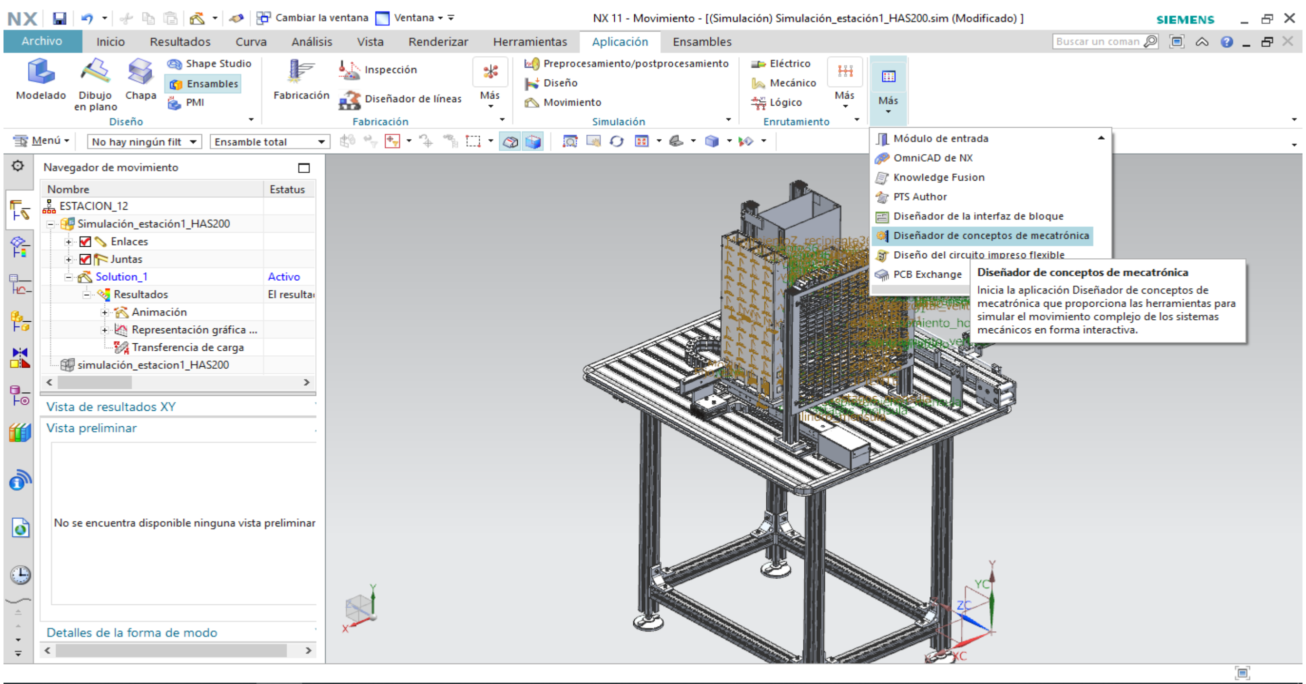
Figure 9. Siemens NX11® program environment.



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2.5. Manufacturing cell assembly

It was performed with the Siemens NX11® program (Figure 9), which has several specialized modules for performing motion simulations such as the mechatronics concept designer, which works with the application of sensors to the components involved in the motion simulation and can be selected after opening a part or an assembly.

3. Automated Station for pellet recycling

The HAS200 allows simulations in which the different types of pellets are mixed and once the practice is finished, it is necessary to separate them by color to store them again separately in the dosing stations. Being highly automated equipment, it was necessary to incorporate within all other autonomous activities the separation of pellets of different colors. Once the different characteristics regarding the optimal design were established, each of the components that integrate the systems that make up the equipment was designed. Using mechanical, electrical, and mechanical drawing analysis software, calculations, material selection, and assembly drawings are developed as follows: Slotted table: Design of structure to support the different systems that make up the modular equipment, this has dimensions, shape, and aesthetics similar to the existing modules in the laboratory. Vibrating Feeder: calculation of the power transmission mechanism and dynamic vibration system, which guarantees the rotational movement of the beads in an organized way towards the conveyor belt. Conveyor Belt: The conveyor belt is selected to ensure the synchronized placement of the beads on the sensor as well as on the blowing nozzles of the sorting and grading system. Sensor: A sensor type is selected for the identification of yellow, blue, and red colors, this sensor is coupled to the PLC control system. Pneumatic sorting system: The pressure and force with which the bead must be ejected into the respective containers is implemented in order not to throw the bead out of the container.

Figure 10. Containers with mixed-colored material.

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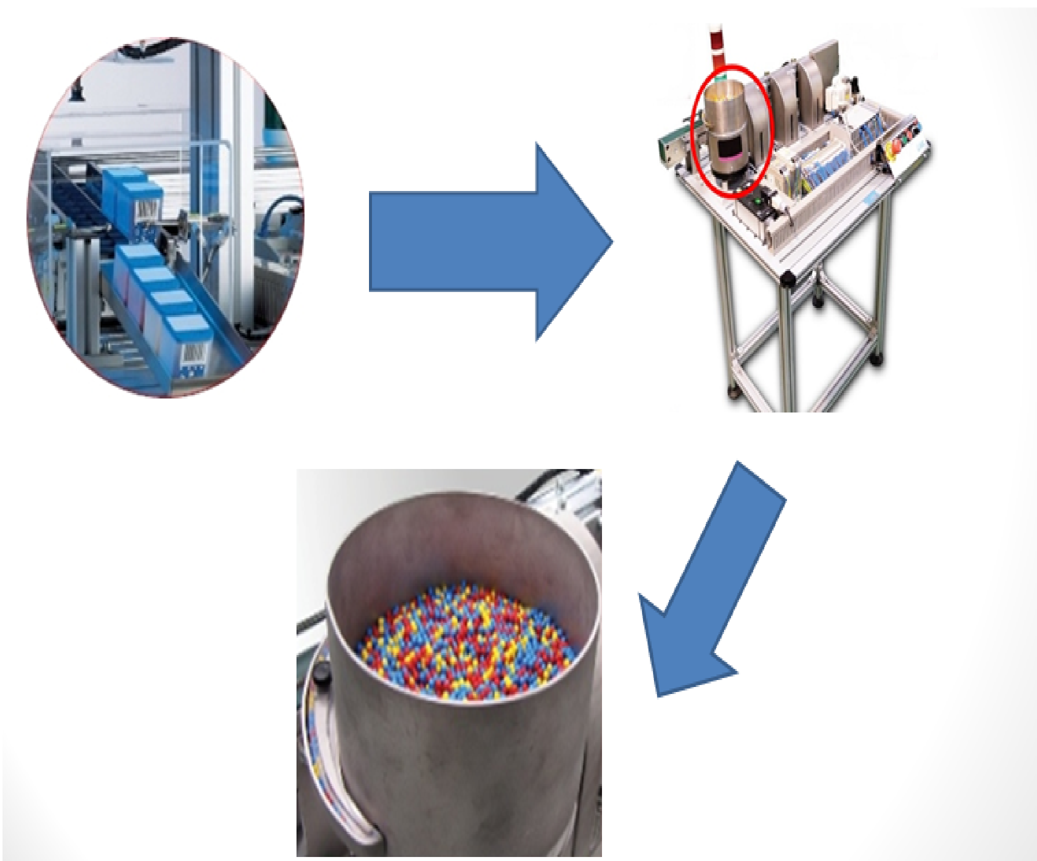
Figure 11. The sequence of work for bead separation.



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3.1. Station design

To simplify the problem, the search for information was divided into systems independent of the equipment and the search was focused on solutions to each system separately. The method used for the selection of the best alternative is the ordinal weighted criteria method. The systems into which the problem was divided are:

- Dosing system. Receives the beads to be sorted and ensures a constant and organized flow of beads to the conveying system.
- Conveying system. It connects the dosing system with the color identification system and then with the sorting system. It oversees transporting the beads to the different devices, in a constant, orderly way, it also guarantees a determined separation distance and a speed synchronized with the speed of the color identification system and the sorting system.
- Color identification system. In charge of identifying the color of the beads by reading light signals emitted by each color, it can generate a deferential response for three different types of colors.
- Classification and sorting system. In charge of receiving the signals from the color identification system and emitting responses that allow the separation of the beads by color.

3.2. Station manufacturing

- Conveyor belt. The conveyor belt is built with aluminum and stainless-steel materials, which are characterized by their resistance to wear and corrosion. Each of the parts that make up the belt is manufactured in such a way that they are flexible and movable, facilitating the possible coupling of the other mechanisms that make up the machine.
- Bead containers. It was manufactured from a 16-gauge stainless steel sheet, which was cut and bent according to the design and geometric dimensions established. Through a milling process, a sight glass system was made to verify the maximum level of beads collected in each container.
- Slotted table and supports. The table was fabricated from slotted plates joined together employing clamping bolts. It is reinforced with profiles at the ends in-frame style. The table is mounted on 35mmx35mm star profile supports that form a four-legged structure adjustable through leveling screws.
- Vibratory system. The storage hopper for the multicolor beads was made from 18 gauge stainless steel sheet, which was cut and rolled into a cylinder shape, the lower part of the hopper was cut into a circle and welded with a TIG (Tungsten Inert Gas) welder. For the vibration system, a 24V DC motor was coupled with two eccentric masses at each end.

Figure 12. General conveyor belt design.

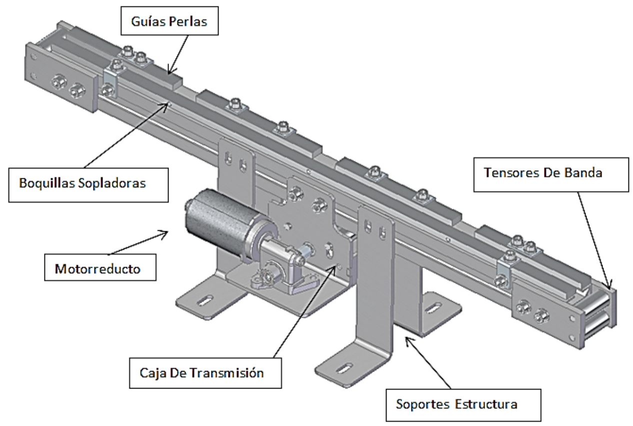

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Figure 13. Separated bead containers and separator hopper.

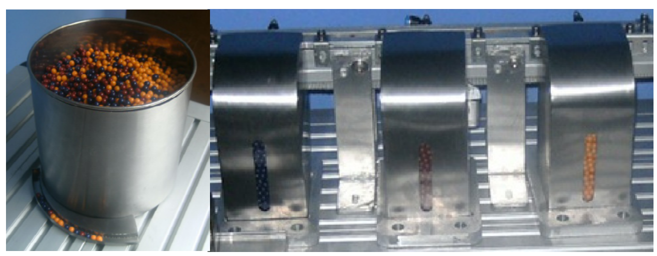

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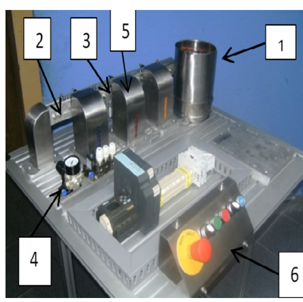
Figure 14. Automated station for bead recycling.



N°	Elemento
1	Alimentador vibratorio
2	Banda transportadora
3	Sensores
4	Sistema neumático de soplado
5	Contenedores de perlas
6	Panel de control

Source: own.

3.3. Control and Visualization

The pneumatic system is connected to the compressed air line of the HAS 200, it contains pressure regulators, 3 solenoid valves, hoses, 3 blower nozzles with flow regulator. Each of the system components is linked to the PLC, which is the control center of the entire pellet recycling station.

4. Robotic Arm Interface

The rehabilitation of the Melfa Mitsubishi RV-M1 arm was carried out using technology already present in the Faculty in the integration of the bead recycling station with the HAS200, each of the parameters proposed was developed.

4.1. Direct Kinematics

It was used to describe the position of the robot in the three-dimensional space using algebraic decomposition taking into account a fixed reference since the analysis is done on the robot, this has a series of links that take their reference point from the fixed part, the solution is reduced to take the angles θ for each link and obtain the coordinates of the points Px, Py, and Pz this can be solved by the Denavit-Hartenberg method using homogeneous matrices where we will have the location of a link concerning the other, reducing to find the homogeneous transformation matrix T (Craig, 2006).

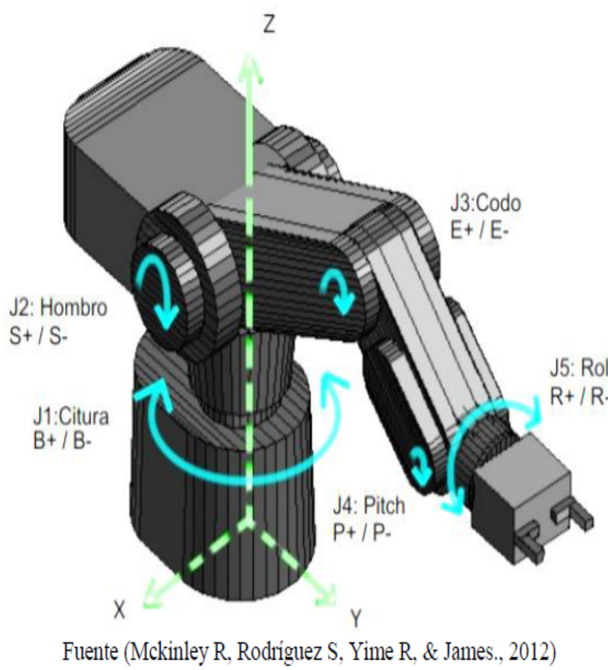
4.2. Inverse Kinematics

The study of inverse kinematics provides a solution to most applications, where it is required to determine the angles between links necessary for a specific position of the end effector. To obtain this given location and orientation a reference is again made to the fixed position located at the bottom of the base. This approach is one of fundamental use for the practical application of manipulators (Craig, 2006). Unlike the solution of the direct kinematic problem, the solution of the inverse kinematic problem is not unique, resulting in the existence of different n-uples q=[q1, q2, q3, ..., qn]T that position and orient the end of the robot in the same way (Barrientos, Peñín, Balaguer, & Aracil, 2007). The calculation of inverse kinematics turns out to be a problem with a high degree of complexity whose analysis and solution process leads to commonly non-unique results (Solano B, 2015).

4.3. Geometric Modeling

The modeling process was carried out in SOLIDWORKS® software, using a student license with an expiration period, downloaded from the

Figure 15. Mitsubishi RV-M1 arm.



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Dassault Systèmes® website. The RV-M1 manipulator measurements were taken using a caliper gauge and a flexometer. The external geometries of the components were drawn, without taking details of their internal characteristics, to be able to create a virtual machine, since they allow the manipulator's degrees of freedom and displacements to be fulfilled. The drawing process was executed in the SOLIDWORKS® "Part" environment, performing the corresponding operations for each element. Subsequently, a verification of the CAD model was carried out following the guidelines of the respective manufacturer's manual.

4.4. Simulation

By activating the SimScape Multibody Link® plug-in in the MATLAB® console, a link to SOLIDWORKS® can be deployed and activated to export the robot model from SOLIDWORKS® to a format recognizable by MATLAB® for further analysis and programming.

5. Automated Gripper

The main virtue of the gripper manufactured is that it can uncover the containers that have been delivered by the dispatch station to empty the containers at the recycling station.

5.1. Robotic Grippers

The grasping and manipulation of objects in industrial processes require special manipulators

Figure 16. Geometric Model Mitsubishi RV-M1 Arm.

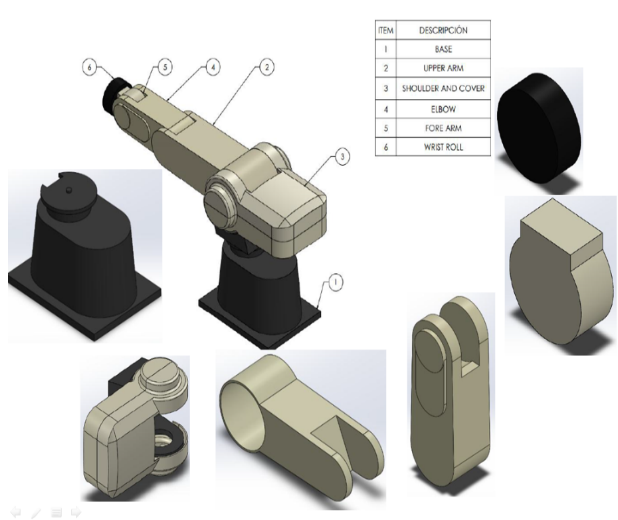

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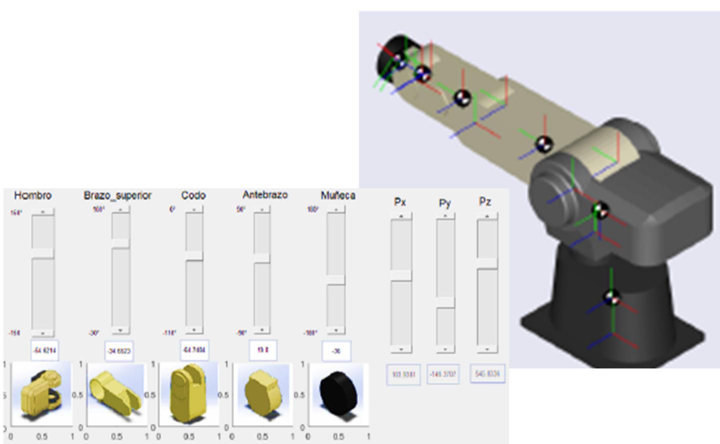
Figure 17. Mitsubishi RV-M1 Arm Interface.



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depending on the robot's operation such as machining, continuous arc welding, spot welding, water jet cutting, spray painting, assembly, and inspection, among others. Some industrial robots have automated devices that allow the rapid exchange of gripping tools, used to compensate for the low adherence of the manipulator to the object, the robots have devices that allow selecting tools in the system according to the need to achieve higher levels of manipulators more evolved in robotics has made universities and research institutions have been studying in recent years, gripping systems similar to a human hand, with emphasis on kinematic modeling, control of the structure and so on.

5.2. Containers Containers

The manufacturing cell containers are made of plastic material (41 mm X 41 mm X 52 mm) with four different types of labels. Each label incorporates a bar code that identifies the product throughout the process and is filled with colored beads according to the configuration established. The containers have a blue plastic lid, as a feature to highlight at the time of being covered the containers by one of its sides protrudes a tab that serves to generate a grip to the operator or in this case to the gripper and facilitate the separation of the lid to the container, within the measures that were relevant for the development of the project it was

Figure 18. Robotic grippers.

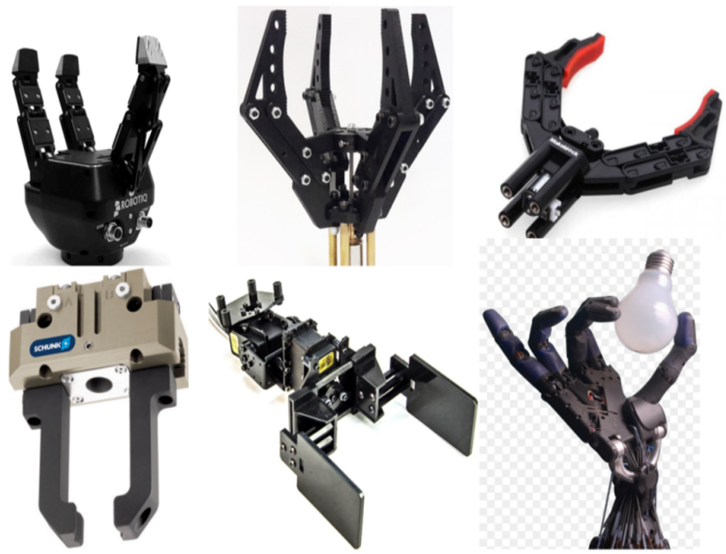

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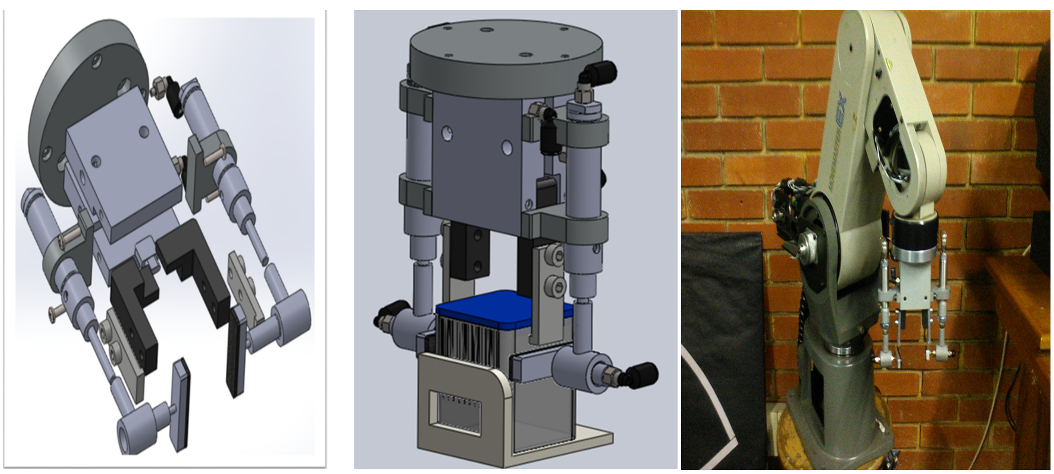
Figure 19. Gripper for handling and opening containers.



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observed that at the time of the arrangement of the cylinders on the palletizing platform the separation between each row of containers is in the range of 4 mm to 5 mm maximum.

6. Machine Vision For Autonomous Transportation

An artificial vision system capable of recognizing a certain existing product in defined positions within the HAS200 was developed. This artificial vision system can recognize products in more than one of the positions of the manufacturing cell as long as the user correctly loads the images of each of the sections into which the cell was divided. For this development, a table was mounted in the work area to avoid identification problems and to have a displacement base for the unmanned ground vehicle. This artificial vision software, developed in MATLAB®, calculates the trajectory of the vehicle and sends this information to the processing unit (Arduino) through the Bluetooth communication protocol for an optimal displacement of the vehicle. The implemented chassis alternative meets the requirements of the development, in turn, the electronic components were selected which are: actuators, sensors, processing unit, and communication module. These components were connected and programmed for the displacement and control of the vehicle.

7. Conclusions

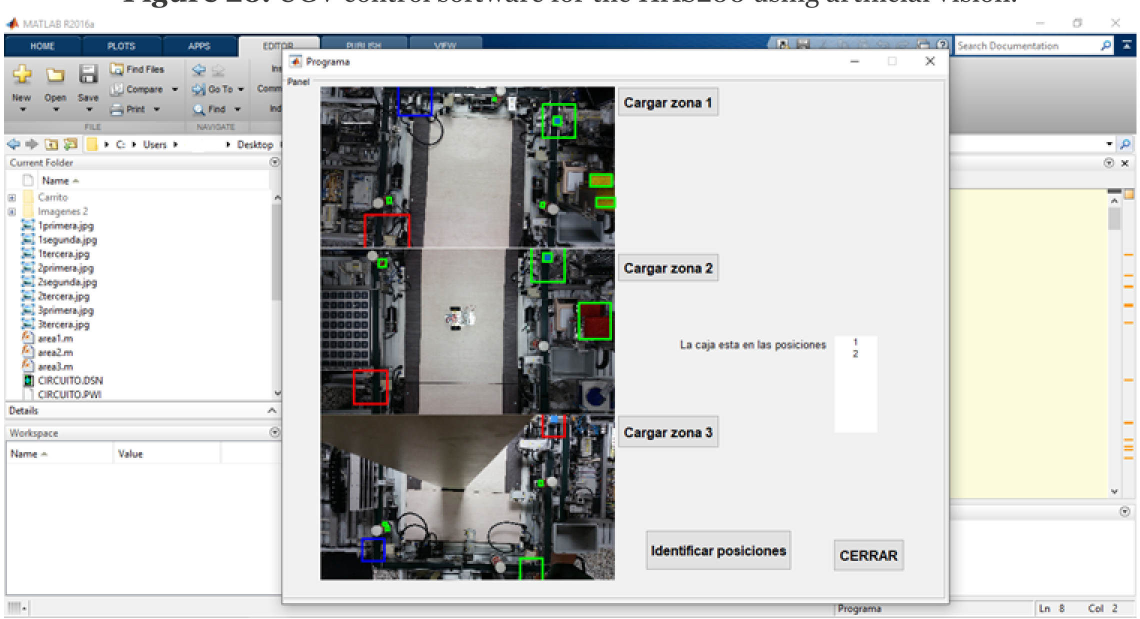
The development of research activities has made it possible to continuously increase the level of autonomy around HAS200, incorporating novel control and automation strategies that, when extrapolated to the industrial sector, propose the technological growth required in the country.

The need to virtualize didactic resources has guided the interest of different research groups, generating successful cases such as the one achieved in HAS200 and its new virtual environment based on geometric models developed in a particular way.

A station for the separation of beads of three different colors was designed, modeled, built, and instrumented for the proper operation of the HAS200. The control of the entire recycling station process is carried out by programming and tuning a PLC, which controls each of the actuators assembled in the workstation.

The interaction between SOLIDWORKS® and MATLAB® programs made it possible to recreate and animate the robot with real conditions, design the graphic environment and subsequently generate a virtual interaction with the robotic manipulator. The process was carried out using MATLAB®, Simscape Multibody Link®, Simulink®, and the Guide control environment, where the geometrical conditions of

Figure 20. UGV control software for the HAS200 using artificial vision.



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the robot that determine its possible positions in the workspace, the solutions of its kinematic chains and the simulation of its movement were established using the respective programming codes, obtaining numerical values in real-time of angles (direct kinematics) and positions (inverse kinematics) for the robot.

The first version of a gripper was implemented for the handling of containers from the HAS200 based on the pneumatic operating principle. The proposal executes the activities for which it was designed and is correctly coupled with the robotic arm and the cell.

The new transportation system based on artificial vision and UGV's makes it possible to generate alternatives for autonomous product mobility that interact with the original transportation system and thus streamline the strategies originally proposed.

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