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# Integration of a Didactic Manufacturing Cell with Different Robot Configurations

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**Abstract:** The present work makes the exhibition of a manufacturing cell for didactic purposes, implemented as part of evaluation in the last cycle of mechatronics engineering formation within Technological University of North Aguascalientes. It includes the motivation that led to planning and subsequent implementation of manufacturing system described, the characteristics of particular processing operations that it was decided to include, methodology to achieve joint work and synchronization of each operation performed, the results of operation obtained and their comparison with initial expectations, as well as the conclusions derived from process, which lead to considering such a project as an ideal model to verify the formation of the future mechatronics engineers, when faced with applications of their area of exercise, reviewing operating principle of mechanical, electronic, control and computing systems to achieve their synergy in a mechatronic system.

**Key words:** Manufacturing cell, robot configuration, didactic prototype, mechatronics engineering.

## 1. Introduction

Technological Universities are characterized by providing their students with an innovative study model that allows the conjunction of theoretical and practical knowledge necessary in the workplace. This is why it is an essential need to provide students with knowledge that can mark a difference in their student and professional life [1]. Under this context, and to verify knowledge acquired during professional training, specifically in mechatronics engineering study program; in tenth training cycle, the integration of a manufacturing cell consisting of multiple transformation operations on a raw material is requested, using various robotic configurations, until obtaining a terminal product with characteristics different from the initial ones. What allows student to develop and apply mechanical, electronic, control and computation systems that is basis of mechatronics [2].

Thus, a flexible manufacturing system (FMS) is defined as a computer controlled system, integrated with automated materials handling devices and computer numerical control (CNC) machine tools, used to simultaneously process a volume of average size in a variety of parts [3, 4]. In case of a manufacturing cell, the number of processing units is usually more limited, however, work is done under the same operating principle. It is clear that to have an FMS, it should start from a set of independent workstations that perform the individual function for which they have been implemented [5] without having any interaction with each other. For workstations integration in a functional cell, it is necessary to have a distributed control system which combines devices control information and that necessary for decision

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making, in order to achieve the management of exchange of resources and processes of production [3].

Said distributed control system must then be capable of supporting characteristics of process controllers employed in each individual workstation, with which intended control action can be effectively ensured. According to distributed control structure, tasks of gathering information from operation and reference variables sending would fall on a central unit whose final communication would be with a computer; in order to provide a user access terminal that so wishes for setpoints modification and in general, to verify the actual process status [6, 7]. This is why it is planned to complement distributed control system action by adding a supervision system that provides feedback on status of each process controller at all times, which is, an SCADA (supervisory control and data acquisition) system, whose term is used to describe a set of industrial control standards to improve complex processes control [8]. Such a visualization system should have the main characteristic of being friendly with user, providing information in a clear and objective manner, in addition to granting the possibility of modifying operating characteristics that user considers pertinent [9, 10].

## 2. Organization of Process Stages

From processes organization proposed in Fig. 1, in manufacturing cell implemented, machining of two part varieties associated with next classification is performed: OK piece and NG piece. Raw material supply to system is done manually, placing the material inside press that is part of machining workstation.

A Cartesian robot is used as a vertical center machining, as shown in Fig. 2, since having linear movement in three axes allows vertical positioning of a cutting tool through its workspace, which forms a parallelepiped, without making a conversion between coordinate systems. It is thus, which from the part subjection in a work-table, it is carried out its processing by material-removal. For which an automatic clamping system was adapted to press that is activated when detecting work-piece, leaving it in right disposition for its processing.

At the end of machining, the SCARA (selective compliant articulated robot arm) robot shown in Fig. 3, performs processed material movement towards conveyor belt, which communicates with the rest of

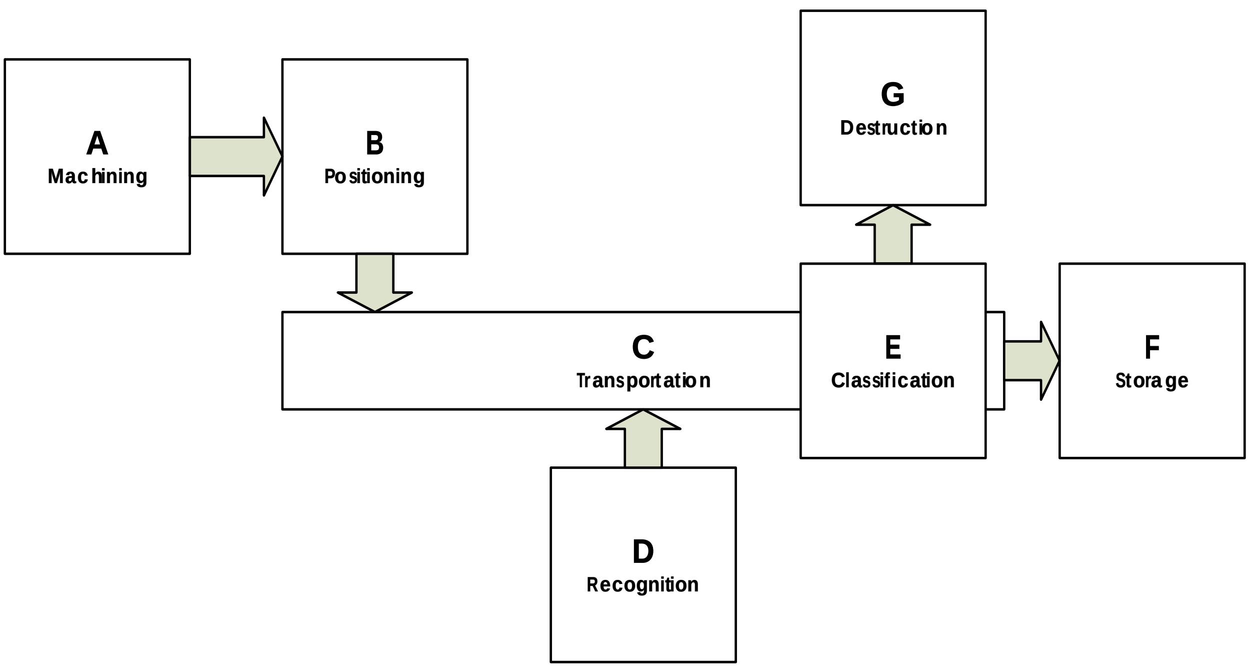


**Fig. 1 Processes organization.**

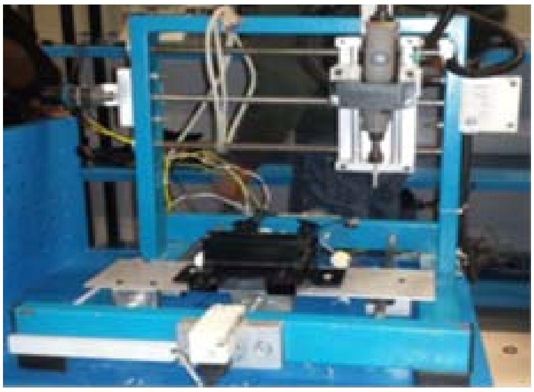

Fig. 2 Cartesian robot.

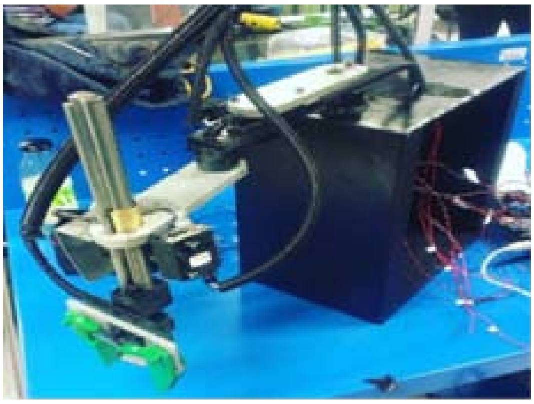

Fig. 3 SCARA robot.

processes through which such piece must pass. This robot configuration is chosen for its ability to maneuver at high speed and precision in a horizontal plane determined by its two rotating joints, as well as variation of vertical position acquired by end effector, in this case, a gripper; adapting to operations that are not performed at same height.

Vision system presented in Fig. 4 makes sure to capture part deposited in conveyor belt while it is kept in motion; determining if it is a OK or NG piece. Installation of a camera is used in end effector of a cylindrical robot, capable of adopting a movement combination between horizontal prismatic and rotating articulations to capture conveyor belt width and ensure part detection regardless of its location and orientation, in addition to using the vertical scrolling to locate the best focus point on that part.

Placed on final portion of conveyor belt is the parallel delta robot in Fig. 5, whose end effector takes advantage of work area under its mechanical structure by acquiring any position over conveyor belt, determined by location and orientation that part retains from subsequent processes. From recognition made in previous system stage, such robot destines the NG piece towards a complementary section that performs destruction of it, while allowing the OK piece to perform its course until conveyor belt end where corresponding deposit is located.

Destruction of NG piece is carried out by the angular robot in Fig. 6, which has a milling attachment as end effector. Its three rotating joints allow itself to quickly reach any position within its workspace, however, when working with Cartesian coordinates it is necessary conversion between positioning systems.

Fig. 4 Cylindrical robot.

Fig. 5 Parallel delta robot.

Fig. 6 Angular robot.

## 3. Integration of Mechanical and Electronic Systems

Each robot has a mechanical structure that provides support and stability to elements that constitute it, as well as end effector which is responsible for development of a specific process within manufacturing cell. Such structures are manufactured in steel and aluminum by means of joints with flat head screws, giving the opportunity to be adjusted or disassembled in case of being required; eliminating the interference with some other element when screw is completely inside structure. There are mechanisms for linear displacement based on use of worm or spindle as a movement driving element towards each axis or link, according to Fig. 7, and that together affect end effector displacement. The type of thread used in spindle is acme, which allows a greater displacement of crown through element in less time, in comparison with UTC (unified threat standard) threads, whose diametral steps are usually be thinner, and therefore, more numerous the amount of threads per unit of distance.

Mechanisms for rotational displacement are constituted by a combination between ball bearings and shafts inside, which allow union between ends of links in which they are adapted. Granting in addition, the freedom to execute independent movement in each link starting from placement of conductive element; and therefore, the timely change of angular positioning. The elements that generate movement, in this case electric motors of direct current, are adapted by a mechanical transmission of speed reduction in each articulation in which movement conduction is necessary. Coupling between motor and articulation is done by means of axle diameter adjustment bushings for an adequate transmission of movement by center alignment, as shown in Fig. 8.

Motor movement management towards its corresponding articulation is done from an individual process controller, an Arduino electronic card that provides an electrical signal proportional to numerical data received with information of position to be acquired by the manipulated link. Sensors adapted to each mechanism perform feedback of position acquired by it. It is through the comparison between signals corresponding to setpoint and feedback that controller determines control action to be applied on actuator in

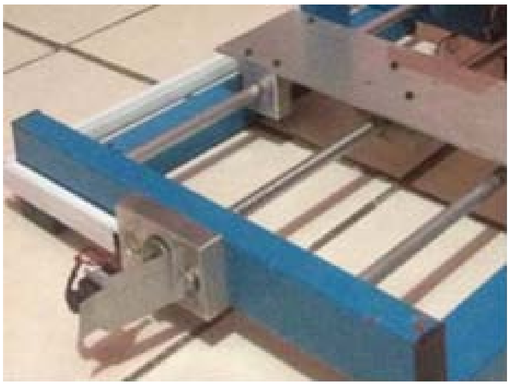

Fig. 7 Linear articulation of Cartesian robot.

Fig. 8 Rotational articulation and motor coupling in SCARA robot.

order to reach requested position. However, direct manipulation of motors through controller would not be possible without use of a power amplifier, which adapts electrical signal transmitted between both sections of electronic system by means of an optoelectronic adaptation. Providing power required for motor movement without putting controller at risk, when the demand for high current values required during the operation of mechanisms that integrate each robot arises.

Each of manipulator robots used in this application was controlled in Cartesian position by their inverse kinematics and local controllers in each joint using PD control technique with gravity compensation, improved with interval fuzzy logic type 2 [11], which are executed each by an embedded system programmed in the Arduino card used.

## 4. Development of Monitoring and Process Control System

Dynamics to perform control and monitoring of each process of the manufacturing cell focuses on use of controller card in constant communication with a graphical user interface by computer; same that is developed in LabVIEW software to perform setpoints management, feedback of position acquired by each robot link when executing a displacement, and manipulation of its end effector, as visualized in Fig. 9.

This controller can be categorized as a master since by means of a serial communication protocol it acquires a data packet coming from the interface [12], which will be divided and sent to each slave controller so that this in turn performs movement management in its respective motor and articulation. Such a system is presented in Fig. 10. Likewise, it is possible to establish a communication in opposite orientation (full duplex) where each slave controller collects position obtained from controlled joints, and transmits it to master controller so that it packages concentrated information and sends it for presentation to user, in the interface developed for that purpose.

This system provides the user with manual and automatic operation modes of the robotic configuration functions used. Manual configuration allows user to move each articulation of the robot independently. This is used for adoption of positions under direct supervision, assignment of action points in the end effector for conformation of trajectories to be executed, and the states that it must acquire for its specific task, such as cutting tool activation, opening or closing the gripper or camera focus, according to the particular treated robot. In case of automatic configuration, user is provided with, through previous establishment of a series of trajectories and states to be executed in end effector, the function fulfillment of the robotic configuration in particular within process performed by manufacturing cell.

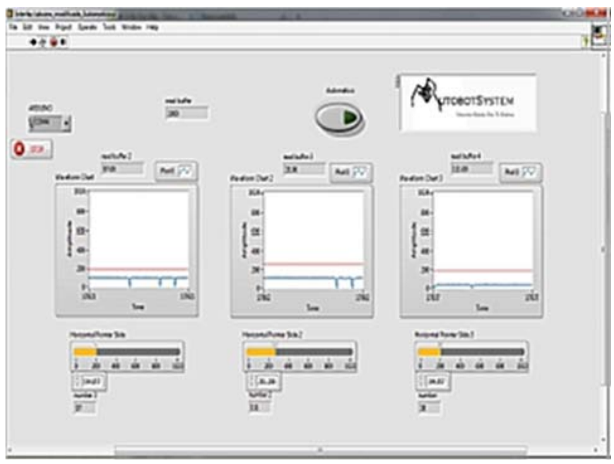

**Fig. 9 Graphical user interface in LabVIEW.**

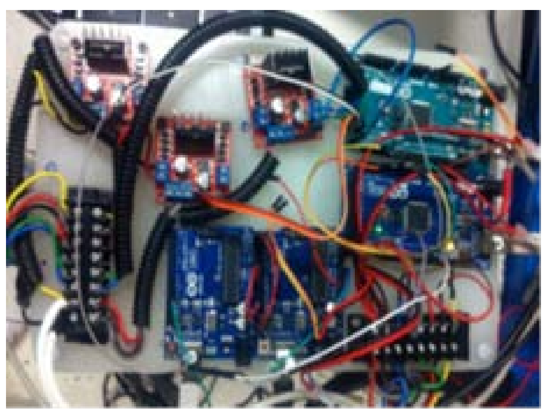

**Fig. 10 Controllers communication system and power amplifier.**

## 5. Integration of Distributed Control System and Processes Communication

Controller of each process makes it possible to ensure its particular function, in addition to acting as a remote terminal unit (RTU) within a distributed communication and control system of total processing operation carried out inside manufacturing cell implemented. Thus, from graphical user interface that each robot configuration used has, it is possible to manipulate and directly monitor operation that it executes, as mentioned before. Under such an interface, necessary conditions for the specific operation are determined during the process accomplishment in which robots are adapted, as trajectories to be described by end effectors, material subjection in the process of machining and positioning of parts, and determination of characteristics for tasks of recognition and classification. To achieve synergy of processes that integrate the manufacturing cell, it is necessary to have a master terminal unit (MTU) that manages them through the application of a distributed control. Through this unit, the activation of each process is indicated according to workpiece displacement inside manufacturing cell, which allows continuous processing of parts.

Communication between processes is possible by means of the assignment of a particular address to the RTU in charge of each one [13], as well as setpoints management and emission of feedback to the MTU. Such data are concentrated and presented to user by SCADA system in Fig. 11, integrated in a computer in permanent communication with the MTU.

## 6. Results of Total Integration of Manufacturing Cell

Particularly for each process that was a part of manufacturing cell, communication between devices ensured at all times the effective action of electric motors used; reaching requested positions either manually or automatically, this due to timely intervention of diffuse PD + G controller, programmed in the Arduino cards used. Thus, from results presented a minimum adjustment was made in order not to register overshoots in the response given by each motor used, as shown in Fig. 12 corresponding to the SCARA robot motors reading: (1) base; (2) forearm and; (3) arm. Regarding exposed signals, Plot 0 corresponds to reference and Plot 1 to output of each respective system.

Communication in master-slave configuration between controller cards played a fundamental role during present application, due to the commitment that meant to maintain complete synchronicity both at process level and at management level. Therefore, it was possible to corroborate the effectiveness of communication between slave controllers and master controller, as well as between master controller and graphical user interface developed for each process;

**Fig. 11 SCADA system of manufacturing cell.**

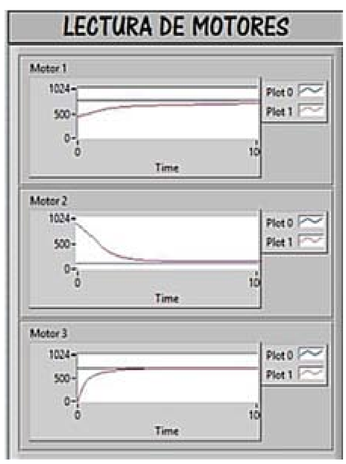


**Fig. 12 Behavior of SCARA robot joints.**

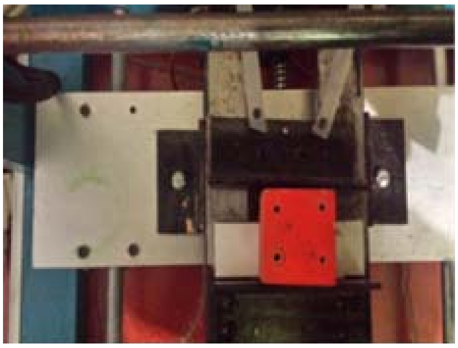

**Fig. 13 Material processed in press of Cartesian robot.**

**Fig. 14 SCARA robot in operation.**

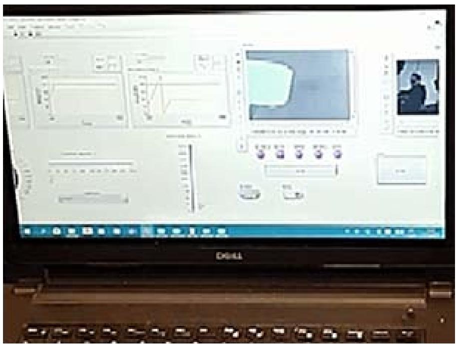

**Fig. 15 Vision system interface.**

**Fig. 16 Delta parallel robot operation for an NG piece.**

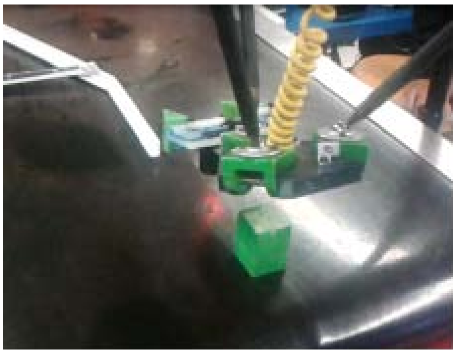

**Fig. 17 Delta parallel robot operation for an OK piece.**

without forgetting to visualize the useful data for developed application: the positions acquired by the articulations and state of end effectors. It is worth mentioning the adaptation and programming of a resting position for robots once they had completed their task, waiting for the signal that would trigger a new activation. Regarding integration of processes within manufacturing cell, machining stage performed its task without distinction of part-type processed, as shown in Fig. 13; executing the simultaneous movement of its extremities to achieve the trajectories that would lead it to fulfill its specific task.

SCARA robot whose function was the manipulation of previously machined workpiece and its positioning on conveyor belt, recorded the proper functioning of each of its joints; maneuvering even though both processes among those which robot performed its action were not at the same height, as shown in Fig. 14.

The adequate performance of vision system in workpiece color identification, for its subsequent classification is shown in Fig. 15, with the timely detection of colors on which it based its function: green for OK pieces and red for NG pieces.

Delta parallel robot task was activated when an NG piece pressed a disposed limit sensor; thus, form the recognition of this piece in the previous section of process, robot gripper acquired necessary position on conveyor belt to take and destine it to destruction stage, without the need to stop conveyor belt movement during execution of its performance. Such behavior is visualized in Fig. 16.

In the case of previous detection of an OK piece, effector did not emit any movement even in spite of detection of disposed limit sensor, as shown in Fig. 17, allowing passage of the same part to the end of conveyor belt where it fell in the corresponding deposit.

## 7. Conclusions

The integration of a manufacturing cell from the beginning, based on development of each workstation, selection and organization of processes to be performed, and the assurance of its total functioning, implies in students of the final cycle from study program of mechatronic engineering, the possibility of applying the knowledge acquired during their professional formation. From the development of this project, approach granted goes beyond operation of a formally constituted system, but it faces the students with what at some point will be their professional activity; complemented their profile with the development of mechanical, electronic, control and communication systems that lead to synchronization and joint work of the subsystems that constitute a manufacturing process, in order to apply multiple transformation operations on a raw material to obtain a terminal product with characteristics different from those of initial material. So the in-depth knowledge of each integrated element was required at all time.

It is not only creation of an independent robotic unit with the characteristics that allow its functionality and manipulation through a computer user interface, but interconnection with others for the reach of a joint objective. So it had to cover and guide the last three cycles of engineering training to achieve the performance results obtained. Likewise, skills that played a vital role during the development of present project are valued, since without disposition of each participating student and an adequate organization of the tasks that each one had to perform, first within his or her team and then in communication with other working groups, it would not have been possible to achieve such favorable results.

The only discrepancy between manufacturing cell implemented and an FMS is the possibility of processing a variety of products, so ensuring this feature can mean the continuity of this work.

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