SUPERVISION AND CONTROL ARCHITECTURE PROPOSAL FOR AUTOMATION AND ROBOTICS TRAINING ON PLATFORM

[1]Ricardo Andrés Castillo Estepa, ricardo.castillo@unimilitar.edu.co
Universidad Militar Nueva Granada, Cra. 11 101-80 (Bogotá - Colombia)
[2]João Mauricio Rosário, rosario@fem.unicamp.br
Universidade Estadual de Campinas, Rua Mendeleiev - Cidade Universitária "Zeferino Vaz" Barão Geraldo
13083-970 (Campinas - Brasil)

[3] Francisco Carlos Parquet Bizarria, fcpb@iae.cta.br
Comando Geral de Tecnologia Aeroespacial – Instituto de Aeronáutica e Espaço Avenida Brigadeiro Faria Lima, 1.941
Parque Martim Cererê 12.227-000 (São José dos Campos - Brasil)

Abstract. *This work proposes a generic supervisory and command architecture for an experimentation modular automated platform equipped with remote access capacities which is conceived with the aim of improve training and research processes on Automation and Robotics, this study describes the platform´s design, dynamic modeling and implementation stages. The technologic and industrial devices integration (Programmable Logic Controllers - PLC, several types of sensors and actuators, image processing, supervisory systems and robotic manipulation devices) in a single platform which is implemented following a modular Collaborative Automatic Production System (CAPS/ADACOR) architecture allows students and researchers to interact with it by means of doing practices in order to successfully automate, supervise and manage a complete production process. Therefore, class acquired theoretical concepts are supported so improving user´s professional skills. A platform developed using the here proposed generic structure allows users to work within an educational environment coping with most of the encountered aspects in a real Manufacturing Automation System, such as Technologic Integration, Communication Networks, Process Control and Production Management. Furthermore it is possible to command the entire assembly process taking place at the platform by a remote network connection using the internet – WEBLAB (Remote Laboratory), enabling individual users and groups in different places in order to use the platform and quickly interchange information. In addition it is important to outstand that both the Modularity and Flexibility of the platform can allow readily any further hardware or software enhancement.*

Keywords: *Collaborative Automation, Integration Architecture, Process modeling, Robotics.*

1. INTRODUCTION

The integration of both industrial devices and modern Information and Communication Technologies (ICTs) motivates the development of new tools focused on supporting the educational formation, allowing the development of new approaches to training on high emphasis technological areas such as industrial automation and robotics (DOMINGUEZ, 2005) (TZAFESTAS, 2006). Within this context, a complete educational and training process focused on these disciplines as well as the theoretical foundations gained in the classroom must be developed in didactic and pedagogic laboratories, so enabling students to develop knowledge, skills and attitudes based on interactive and motivated interaction taking into account related areas of technological knowledge (D'ABREU, 2002) in such a way as preparing competent professionals for the job market. This constructivist development of learning activities on Automation and Robotics also offers a conducive environment for researchers in these areas to formulate and assess their hypotheses (CHELLA, 2002) (YU, 2003).

Currently there are several manufacturers of automated devices aimed to support training and research in technological areas; these devices provide some functionality in their control systems. However, most of these platforms are expensive, do not have open architecture for developing new experimental practices nor cover the needs required by researchers. These researchers often avoid the previous proprietary and mechanical the limitations by investing a lot of time in adaptations that can harm their research results. It can be pointed out situations in which because of these devices or platforms do not usually incorporate more than two technologies, the range of experimental applications that can be performed on them becomes limited to only one knowledge area. Consequently these activities do not reflect conditions normally experienced in the current industrial context reality, where increasingly the automated manufacturing facilities require the technology integration from conception to implementation and maintenance. Similarly, both the proposal and research activities results are limited to very specific academic fields.

Also, nowadays, many platforms on the market do not provide supervision nor remote control (LAN / Internet) capabilities, therefore they only provide possibilities to perform practices with fixed schedules and with a pre-established duration and organization. Thus, the use and exploitation of these devices become restricted to a small number of people (SAIRE, 2008), (ARIZA, 2008). Due to the change from a local economic perspective to a global economy, since the last decade of the twentieth century manufacturing environments have evolved in its economic, technical and organizational dimensions causing trends in industrial automation have to adapt to a need for small and medium production, with an increased differentiation of families of parts and / or products, which are almost customized to the needs of individual clients and also add value to its intangible component (software, support services including, online support line, etc).

Thus new paradigms such as Collaborative Manufacturing Management (CMM) and consequently the Collaborative Automated Production System (CAPS) appear as an evolution and response to new needs that are not met completely by the original concept of (Computer Integrated Manufacturing) CIM, which provided Automation Production System (APS) with a very small degree of hardware and software flexibility and integration, based on a strongly hierarchical and centralized control architecture and in a sequential planning framework which did not allow these systems to adapt quickly to environmental changes.

Besides improving the previous features (flexibility and possibility of integration) and agility, the CAPS add modularity, fault tolerance, reusability, and interaction between production management components within production systems. Thus the CAPS can achieve both the global and local manufacturing objectives, based on a structure no longer hierarchical but heterarchical. This new approach is based on development and integration of emerging technologies such as object-oriented control (decentralized), Intelligent Manufacturing Systems (IMS) and Mechatronics (Fig. 1). The distributed and decentralized characteristics of CAPS modular control architecture require the implementation of local and remote supervision and control capacities (COLOMBO et al., 2004).

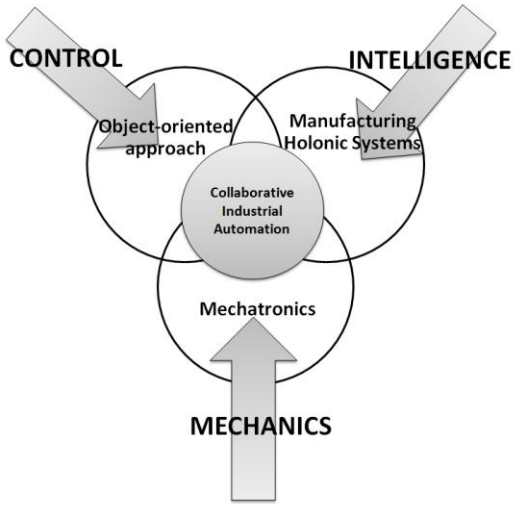


Figure 1. Collaborative Industrial Automation

Within the IMS, the Holonic Manufacturing Systems (HMS) have a holonic or holarchical structure that causes the CAPS have a high modularity (hardware - software) that allows both the autonomy and the cooperation between different holons, which are controlled in a distributed way (VAN BRUSSEL et al, 1998). Therefore, the HMS enable auto-configuration capabilities and ease of expansion and modification. One of the architectures proposed in the literature in order to exemplify the approach HMS / CAPS is the collaborative architecture ADACOR (ADAptive holonic Control Architecture for distributed manufacturing systems) (LEITÃO, 2004) which is described below.

The reliability, flexibility and agility of a CAPS not only are conditioned by the reliability, speed and flexibility of their individual mechatronic components, but depends crucially on the reliability and flexibility of the control and automation architecture (hardware). A CAPS with an ADACOR architecture organizes the use of their modules (holons), synchronizing the resource utilization, being dynamically reconfigurable, and thus capable of producing a large number of products and / or families of parts with minimal effort to change their components physical (flexibility). Thus a CAPS / ADACOR can easily adapt to a stochastic manufacturing environment, characterized by frequent occurrence of unexpected disturbances (LEITÃO, 2005). The collaborative control architecture ADACOR was proposed, developed and implemented at the Polytechnic Institute of Bragança (Portugal), taking into account a set of holons (definition given below). Currently in order to complement the theoretical instruction, the Higher Education Institutions (HEIs) implement various strategies in order to provide students with the integration of the technologies used in industrial environment (Fig. 2).

The design and implementation of automation platforms focused on education is mainly developed within the HEI and research centers, an example of such applications is the PIPEFA platform (Platform for Industrial Training, Research and Training on Automation) implemented in the Laboratory of Automation Integrated and Robotics (LAIR) at the Campinas State University- UNICAMP (IORIO, 2002) in order to demonstrate the products assembly and disassembly processes, in the LAIR laboratory has also been developed and implemented a Production System (PS) architecture learning platform for colors mixing (AIHARA, 2000).

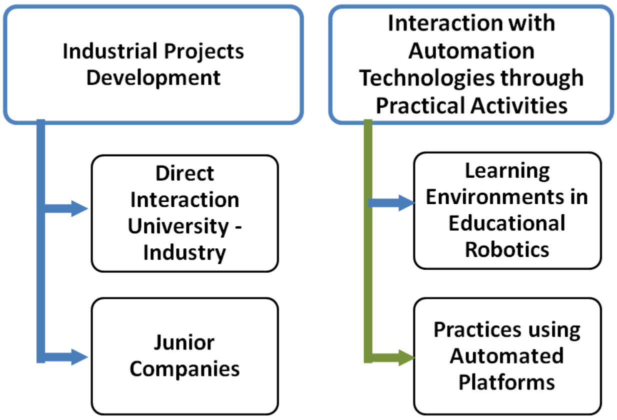


Figure 2. Ways to Support the Formation Process and Automation Research

These two applications, composed of different workstations comprise PLCs, sensors and actuators used frequently in the industrial environment. In Baffi (2001) is described the design and implementation of a collaborative platform formed by two manipulator robots and a belt conveyor used as a transfer and union element so constituting a PS that allows experimental practices in order to provide training in industrial automation. In D'Abreu (2002) are presented three projects developed with the aim of creating integrated learning environments in automation using development kits, LEGO Mindstorms, and ROBIX™: system for transport products in a production line, automated production and a solder machine.

At the Santa Catarina Federal University was developed a didactic platform for working with electro-hydraulic actuators to allow students to carry out experimental and theoretical analysis, this platform includes PLCs, a hydraulic power unit, a platform for circuit assembly and system acquisition and a control VXI / LabVIEW™ (DE SOUZA, 2007). The Sao Joao del Rei Federal University in partnership with Junior enterprise EJEL developed academic support platforms in industrial automation field (BARBOSA et al., 2006), the Paraná Federal University of Technology has implemented a programmable control system for distributed systems based on a FESTO ™ modular production system (SELESKI, 2006) in order to automate a process and apply concepts of tasks distribution to avoid centralized control.

The proposal of technology integration in a single generic architecture application presented in this work is validated through the modeling, analysis and development of an automated experimentation platform that will offer the possibility to implement practical applications due to the modularity and flexibility of the proposed architecture. These practical activities will use the integration of different technologies, rather than individual technologies normally used in conventional courses of Automation and Robotics. The holonic architecture of Collaborative Automated Production System - CAPS / ADACOR proposed in this work will enable users to do complete hands-on experiments within a learning environment that exemplifies routine tasks in modern Industrial Manufacturing Systems (Transport, Classification, Assembly, Inspection, Quality Control and Supervision).

2. CONCEPTION OF THE PLATFORM ARCHITECTURE

The educational foundation that motivates the interaction with industrial technologies through the implementation of practical activities in order to effectively support the processes of training and research on Automation is based on Jean Piaget's cognitive theory of CONSTRUCTIVISM, which proposes that knowledge is not something that can be transmitted, but is constructed in a personal way through experimentation and manipulation of individual objects of study, building new concepts based on previous (SEITZINGER, 2006).

From this latter approach, an effective strategy to provide a practical complement to the training process on Automation and Robotics is the interaction of students with industrial technologies through integrated learning platforms that enable the realization of practical experiments with various industrial devices. This strategy is taken into account in this work requires of these platforms having a hardware and control architecture that can represent the current APSs in order to faithfully exemplify the industrial problematic. Thus, these activities will illustrate practical situations usually found in professional practice, developing in students not only theoretical knowledge, but also technological skills to deal with the job market. The completion of these activities may be in hands-on or via the Internet (DOMINGUEZ, 2005).

In the case of collaborative platforms WebLab integration is an ever-growing area, and there is no a standardized architecture that directs the implementation and control of these devices (TZAFESTAS, 2006), in many cases this architecture depends both on the type of technology to be integrated and on the type of experiments to be performed. Taking into account the current direction of industrial automation development and aiming to design an experimental tool in Automation and Robotics, it can be identified the problem and the scope of study where the platform will be used. After studying industrial technologies that can be integrated on Automation and Robotics it is proposed a hardware - software ADACOR holonic type architecture.

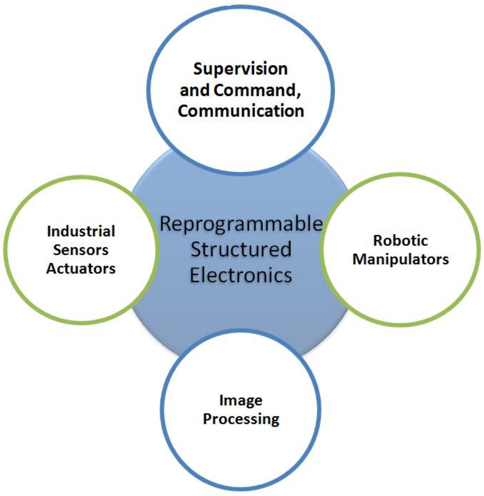


Figure 3. Technologies Integrated in the Platform

The selection of technologic integration architecture is considered from two perspectives: a technological and a pedagogic points of view. From a technological perspective, the integration of the five above described technologies aim to achieve a faithful representation of the CAPS architecture that orient current manufacturing systems implementations. It should offer not only the possibility of centralized control, but also allow some level of autonomy between sub-system components without completely losing the collaboration and cooperation between them (distributed or decentralized control).

Provided that, it is looks for a generic structure in its operational and command parts having a high degree of flexibility, modularity and reconfigurability, being open (hardware - software) to any future improvement or modification of both the operative or command part (structure and programming logic) and easily scalable. It also designed a module for online command and monitor the functioning of the platform, so providing for the user feedback and video data, thus allowing the processes configuration. The flexibility of the proposed structure will be reflected in: the possibility of reprogramming the structured logic used in implementation, the possibility of assembling different products using the same platform, and the reconfigurability of the physical structure. The integration scheme proposed for the platform can be seen in Figure 4.

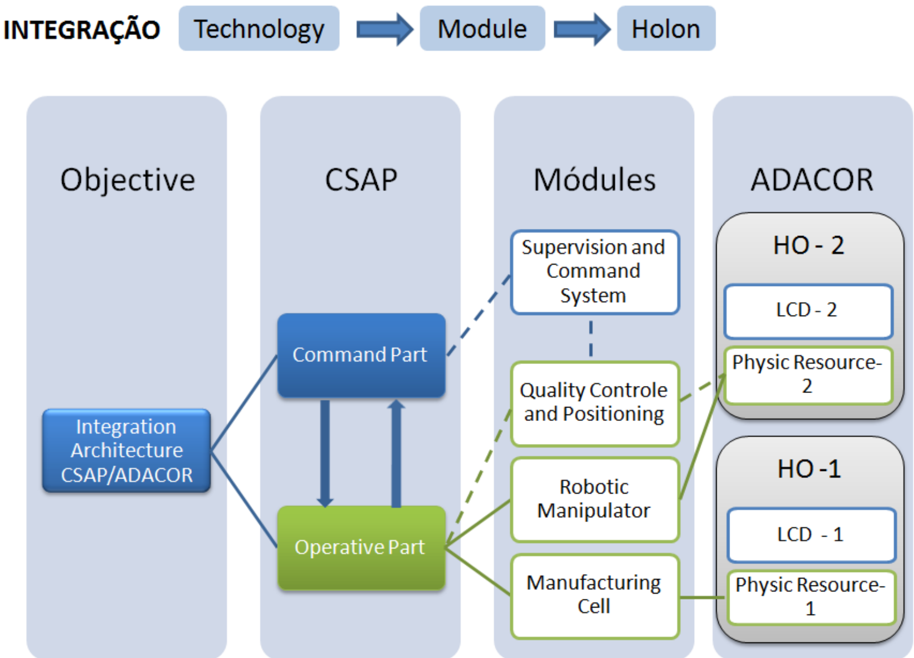


Figure 4. Proposed Integration – Collaborative Automated Production System with Holonic type (CAPS/ADACOR) Architecture

The proposed integration is designed through an architecture in which each of the five industrial technologies described in Figure 3 is exemplified through a module, and these in turn are integrated through two levels of modularity, in a first level (macro) these are associated to form an Collaborative Automated Production System CAPS, and still looking for a greater consideration of modularity in a second level (micro) this concept is also brought to the interior of the constituent parts of the CAPS. This is achieved by defining fully functional agents which will be integrated into a holonic type heterarchical architecture - ADACOR (LEITÃO, 2004). Inside the platform, these agents called holons are composed of a physical resource and a Logic Control Device (LCD) that can be programmed in order the holon to execute processes independently but collaboratively achieving shared goals, then the integration is managed in a higher level by supervision and control system of (Fig. 5).

3. IMPLEMENTATION OF PROPOSED PLATFORM

In order to validate the proposed ADACOR integration and the modeling of sub-processes designed to be performed using this architecture it is implemented both hardware (PC) and software (PO) parts of an automated platform (Fig. 5) in which each sub-process is specified and implemented in PLCs. In this sense, to evaluate not only the modeling of each holon, but also the integration of data, we propose and implement a complete process comprising classification, assembly, inspection and products transfer, each one with an associate sub-process. This integration is specified through a GRAFCET graph in order to implement it later using ladder logic in industrial PLCs in the same way as were performed the Petri Nets (PN) modeling.

3.1 Operative Part (OP) - Description and Implementation

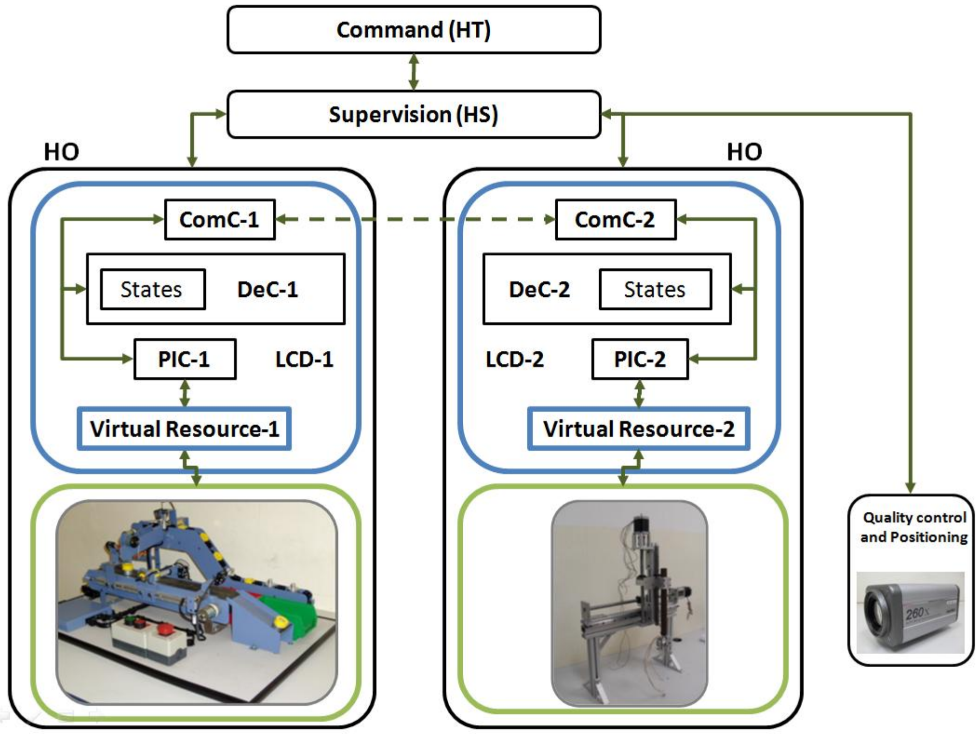
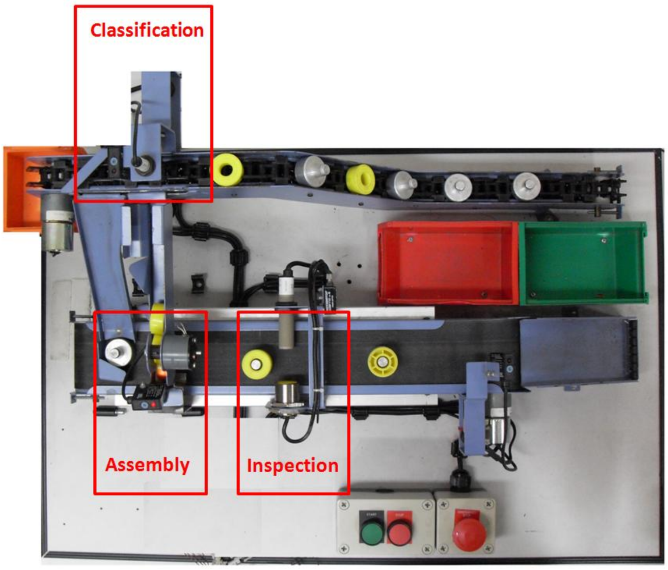


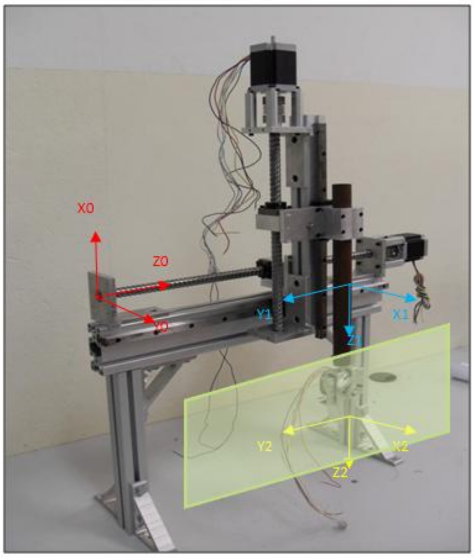
Figure 5. Proposed Platform - Integration Diagram

3.1.1. Manufacturing Cell

The manufacturing cell integrated into the designed platform as validation of the proposed structure corresponds to the ICT-3 model of the BYTRONIC ™ company (Fig. 6a). This are composed of sensors (4 inductive, 4 photoelectric and 1 capacitive) and actuators (2 DC motors and 2 solenoids, ON/OFF and emergency switches). This operative equipment, properly programmed allows the realization of assembly and inspection of a product composed of two types of parts (a metallic base made of aluminum and a plastic ring that is put over this base). In the manufacturing cell, originally the pieces have to pass along several consecutive stations: Classification, Assembly, Inspection and Rejection. In the proposed architecture presented in this work only will be used Classification, Assembly and Inspection the stations.



a) Manufacturing Cell



b) Robotic Transfer System

Figure 6. Platform Operative Part

3.1.2. Robotic Transfer System

The robotic transfer system consists of a cartesian manipulator (Fig. 6b) with two degrees of freedom (DF) each one driven by a stepper motor allowing translational movements: lateral (X direction) and vertical (Y direction). This robot is designed for feeding and transfer parts or assembled products, after it pass through the quality control module. The products are taken from the belt conveyor and transport towards a storage area if they get correct, otherwise they are removed by the manipulator which move the individual parts to the supply chain on which they can be inserted so starting again the process.

3.2. Command Part (PC) - Specification and Implementation

For the complete PC implementation of the PC was performed as first step the substitution of the electronic control board in the manufacturing cell, this board was originally supplied by the BYTRONIC™ company. This interface allowed as user interaction merely the activation or deactivation of some sensors, therefore it was replaced by a physical command interface based in structured reprogrammable electronic in order to develop a fully reconfigurable architecture, open to future modifications.

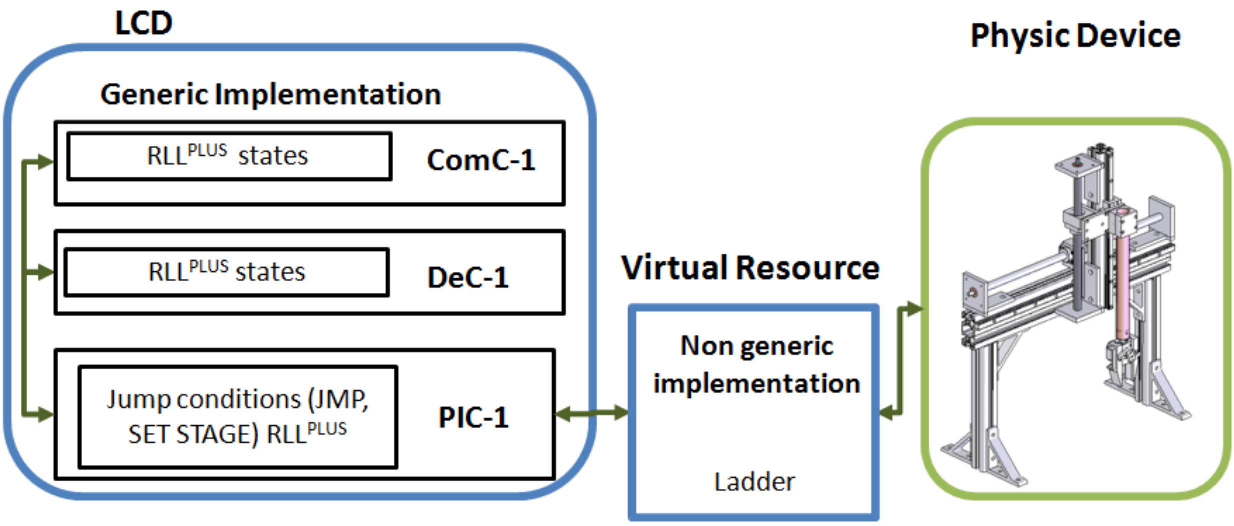


Figure 7. Scheme for ADACOR Operational Holon Implementation

3.2.1. Command Interface Implementation – CAPS / ADACOR Architecture

Aiming a holonic implementation of PC, 2 Programmable Logic Controllers PLC are used, each one focusing on the control of an operational holon. Each PLC implements completely the holon's LCD (Logic Control Device) with its decision, communication and virtual resource part following an ADACOR architecture.

Taking in mind this division of responsibilities it can be achieved a high level of modularity and therefore the possibility to reconfigure and work faster and easier with any of the holons of the proposed architecture. So, in addition it means in FLEXIBILITY based on the ability to propose and implement various activities that can easily be made for training (on automation using the manufacturing cell, on robotics using the robotic manipulator or on mechatronics using the integrated system). Taking this holonic architecture into account it is possible to test different network communication models between the proposed holons, further extending the platform usefulness. Figure 7 shows in detail the scheme implemented to integrate each holon following the ADACOR proposed architecture.

3.2.2. Implementation of the Supervision and Command Module

This module corresponds to the HS and HT holons. The supervisory system provides information about the state of significant variables of the process through indicators on a schematically screen, thus informing the user about what is happening in the platform operative part and allowing him to command the OP by means of controls to obtain a desired functioning, this system emulates a Virtual Instrument (VI). Figure 8 shows the Supervision and Control module in LABVIEW ™ environment.

The supervision and control software was structured through basic functions blocks, which are created in a modular way taking into consideration the following phases:

3.2.3. Quality Control and Positioning Module - Design and Implementation

This module is associated to the supervision and control system to enable the integration between the two operational holons, so offering the possibility for detection of products that are differentiated by color of the plastic ring above the metal base. Therefore, the use of this module associated within an integrated process allows the development of various activities in mechatronics, adding flexibility to the proposed activities with the platform.

The image processing algorithm developed for the quality control system allows the detection of different materials while they are moving through the belt conveyor as follows: a metallic base without a ring above, a correctly assembled product (the color of the ring above the metallic base determines whether the product is correct or not) and an incorrect assembled product (the color of the ring is not the determined by the user).

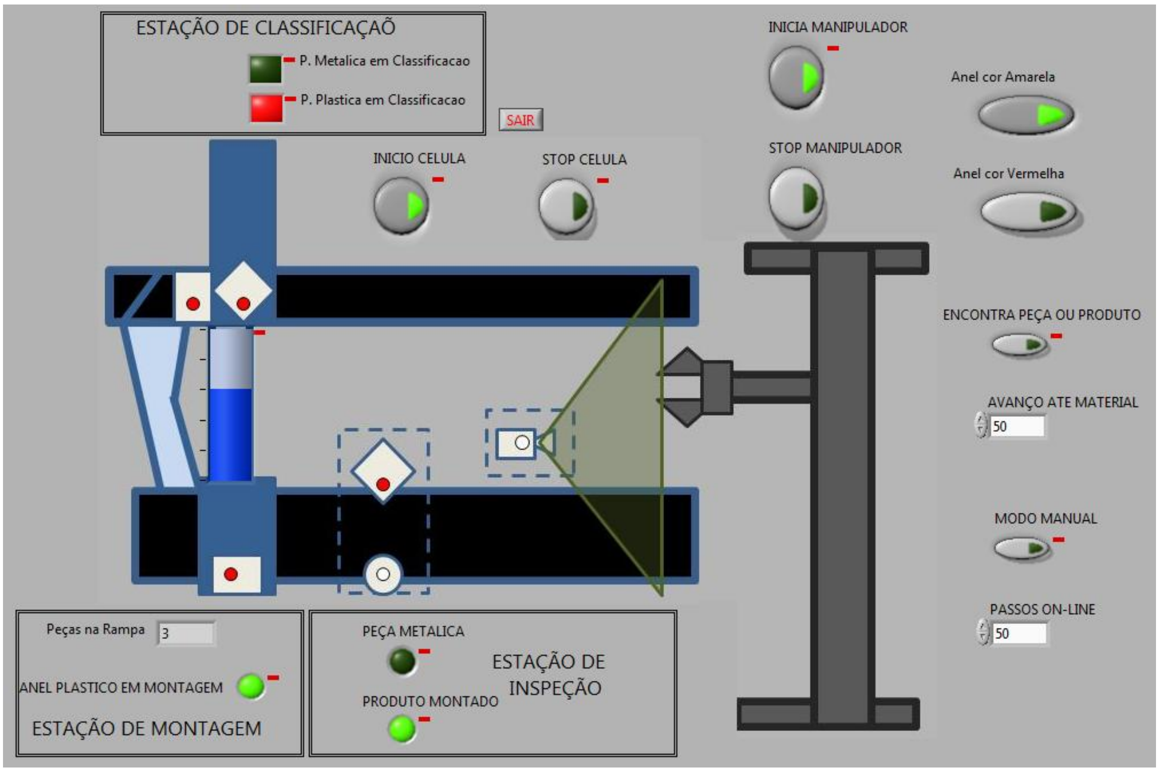


Figure 8. Virtual Instrument developed for Supervision and Command

Besides the images processing to classify materials, this system detects the product's position with regards to the first DOF of the manipulator, this position is then compared with the manipulator current position (determined by its kinematic model), for this robot minimizes the error and get the part. Thus when the system detects any material on the belt conveyor it will inform that to the supervision module in order to it stops the movement of the conveyor belt until the manipulator takes the material, carry it to the appropriate area and then return to its home position. The quality control system check the information delivered by the inspection station, and when necessary can also function without depending on this. The quality control system output information could also be used in a statistical way in a future work in order to test and explore production management models.

4. USE OF THE PROPOSED ARCHITECTURE FOR FORMATION AND RESEARCH

The possibility for propose practical activities in these areas using the platform integrated following an ADACOR architecture is based on two main features: flexibility and modularity. Based in these characteristics, each operational holons provides the possibility to propose practices focused on one goal area depending on the technologies comprising it: the manufacturing cell holon in automation and the robotics manipulator holon in robotics.

The platform proposed and implemented following a holonic hardware - software architecture allows the realization of experimental activities exemplifying tasks encountered in modern CAPSs. This work is validated in two ways: through the modeling and dynamic analysis of proposed operation to ensure achievability of its sub-processes, and through a hardware - software implementation of a real platform that follows an ADACOR architecture specifying and then implementing the proposed sub-processes in structured reprogrammable logic.

As a suggestion for future works, it would be consider the use of the proposed modular, flexible and fully functional architecture, and from this point further study new or improved training methodologies using this tool in order to develop in the students skills on technologic areas, it is important to emphasize that a profound pedagogical study is beyond the scope of this work. However, below are presented the first approximations of how to use the platform, describing some examples of activities that can be proposed and implemented within courses on automation and / or robotics.

Taking into account the modeling modularity and the hardware-software implementation, further to the possibility of experimentation with each holon separately it is also possible to define activities within each of them considering the basic operation units or sub-processes, which represent tasks similar to those found in CAPS and whose implementation has been already validated as feasible through the PN modeling. These sub-processes can occur within the smaller hardware units called stations (Tab. 1).

Table 1. Tasks available in the Proposed Architecture

Tasks with the Operative Part	Tasks with the Command Part
• Supply of raw material • Classification of raw material • Products assembly • Products inspection • Quality control • Transport of finished products	• Individual processes monitoring • Counting of pieces and assembled products • Manufacturing Scheduling of more than one product • Monitoring and control of integrated processes

Thus, with the proposed architecture it is possible to propose practical activities with three levels of complexity (experimentation and validation) in order to apply the theoretical knowledge acquired in the classroom:

a) Level A: Focused on knowledge about the operation of sensors and actuators and their application in individual tasks, using physical hardware, sensors or isolated actuators;
b) Level B: Focused on the sub-processes implementation, this can develop individuals or integrated tasks using individual or associated stations to form a holon, so composing complex operating procedures;
c) Level C: Focused on complete processes implementation, integrating the holons in a CAPS that performs defined production activities in order to meet a production demand.

The aim of Level B practices that can be proposed is based on the initial and final markings in a station PN (Petri Net) model. In the case of practical activities integrating various stations, even from different holons, is it defined as general objective of the activity to attain the state corresponding to last station desired marking, starting from the first station initial marking. In order to select the stations to be integrated, it should be considerate that the outputs of a station are connected to the inputs of the next, so the number of outputs from the first station should be equal to the number of inputs in the second. To propose Level C practical activities it must be integrated two complete holons in a CAPS.

4.1. Proposed Activities within the Automation Course at Campinas State University

As a first approximation for using the platform were proposed two activities that were realized by the postgraduate students of the discipline IM333 – Logic Programmable Controllers at the Campinas State University in the first semester of 2010, these activities developed in this work include an active experimental component to complement the concepts presented about tasks programming using structured reprogrammable logic. Below are presented the two activities.

4.1.1. Activity Implemented with Classification Station of the Manufacturing Cell

The activity developed in the course was active type - PBL (Problem Based Learning) and is classified according to their complexity as level B activity. This activity is based on the specification and subsequent real implementation of a possible sub-process, using the hardware equipment of the manufacturing cell and the implemented command interface according to the proposed architecture.

The sub-process at the station starts when the metallic and plastic pieces are moving through the supply chain towards classification station.

a) If a metallic part (base) is detected at the classification station, there will be no action until it can cross completely the station and reach the ramp to the belt conveyor;
b) If a plastic piece (ring) is detected at the station, it should be pushed to move by the corresponding ramp.

4.1.2. Activity Implemented with the Robotic Transfer System

The activity developed in the course was active type - PBL (Problem Based Learning) and is classified according to their complexity as level B activity. This activity is based on the specification and subsequent implementation of a real task, using the robot manipulator and the command interface together implemented under the proposed ADACOR architecture. The task be programmed by the students is stated as follows:

a) Moving first and second stepper motor to advance and retreat the two DOF of the manipulator in a sequence that causes the end effector describes a square;
b) Repeat the first sequence for the end effector in order to it describes a smaller square inside the first.

5. CONCLUSIONS

In this research it was proposed a supervision and command generic architecture for an automated modular experimentation platform with capability to be used in remote form, designed to support and complement formal education and research on Industrial Automation and Robotics by designing, modeling and implementation a holonic-ADACOR type architecture to integrate technology into an automated platform, in which can be proposed activities that will illustrate CAPS routine tasks used in the modern industrial environment.

The flexibility and modularity characteristics were considered in the conception of this architecture taking into account two perspectives: technological and pedagogical. The possibility of distributed functioning and control of this architecture, the hardware - software reconfigurability and scalability, and the use of structured reprogrammable logic promote a variety of practical activities, which enhance its complexity level as it increases the degree of integration within the platform. In addition, the possibility of remote laboratories promotes practical activities from a distance, so enhancing the use range of the platform.

Two practical activities were propose to illustrate the use of the platform, which were developed by students of a postgraduate course. Accordingly, groups of students had to specify and then implement a task in each holon using the corresponding PLC. The student groups expressed an interest in activities development by reviewing and deepening the concepts studied in theoretical sessions, motivated by visualization of operating hardware functioning. This was made possible due to practical applications were not isolated, but immersed in a truly functional and accessible for students platform.

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