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Reliability and Flexibility of Peripheral Connections in Robot Assembly Cells*

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Although virtual robotic laboratories can be suitable for the teaching of robotics at a basic level, in-depth and, above all, more professional learning requires a real knowledge of the robotic cells and a direct contact with their components (robot arm, controller, programmer, input and output devices, etc.). In order to improve the practical teaching, a prototype of a functional module for the connection of inputs and outputs has been designed and manufactured. The developed module improves the performance of the cell in precision assembly operations as it simplifies the robot's communication with the peripheral sensors, allows a quick adaptation to the changes required by the cell and rationalises the methodology for the connections. The tests made with the connection module have shown that the tool has a wide scope for university teaching of manufacturing cells as it enables the students to understand clearly the multiple connections of the devices to the controller, allowing the system to be handled safely and simplifying the programming of its operation.

Keywords: robots; assembly cells; input–output interface; teaching

INTRODUCTION

NOWADAYS robots are frequently used in numerous fields in industry, and in certain manufacturing processes they have become almost essential. The industrial robot, by definition, is multifunctional and can be applied to an unlimited number of functions. In addition, the already deep-rooted typical applications (welding, palletisation, painting, etc.), its use in other fields, such as that of assembly, can become a competitive advantage with respect to cost and time saving.

Assembly applications present great difficulties for their automation-using robots due to the precision and complexity of the movements that are usually required. Although many of the packaging processes are carried out using special very quick and precise machinery, the current market requires flexible systems that allow the introduction of frequent modifications in the products at minimal cost. Additionally, current environmental legislation encourages manufacturers to develop efficient technologies making the dismantling and later recycling of the components easier. Therefore, industrial robots become the best solution for many of these applications. As the assembly and dismantling operations are a considerable part of the product costs, considerable effort is being made in research and development in this area [1–3].

The design and implementation of flexible robot cells in the field of manufacture and assembly generally requires the use of sensors to provide the cell with the necessary information about the environment for both the robot and actuators to carry out their work with the precision and reliability level required [4–6].

In the case of simple cells, the control of the same can be carried out from the robot controller itself. For this, the robot controller includes a series of inputs and outputs (I/O) by means of which the necessary connections can be established, necessary either to receive the control signals from the cell sensors or operate the external devices of the same. These ports, available in most controllers, are usually called GPIO (General Purpose Input/Output). Access from the outside to these ports usually consists of a multiple-pin connector, for example 50, with a configuration that usually includes supply pins, earth pins and various inputs and outputs, usually 16 inputs and 16 outputs.

The direct use of this connector for the inputs and outputs of signals is on the one hand laborious and delicate (with respect to the simplicity and flexibility of changes in the outside devices) and, on the other hand, the controller may have been exposed to incorrect or accidental connections that may damage the it due to excessive voltage, surge, noise, etc. [8–10].

In order to improve the robot communication system with the peripheral sensors, a prototype of an I/O connection functional module has been designed and manufactured. The main objectives of this module are as follows.

1. Allow easy communication between the controller and the external devices of the cell providing great flexibility in the assembly of these devices.

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2. Guarantee the safety of the controller operation independent of the elements connected to it.
3. Allow the connection of power elements to the controller without electrically perturbing the controller I/O circuits.

Apart from these objectives, the connection module is a tool with wide teaching scope at third-level university teaching of manufacturing cells as it enables the students to clearly understand the multiple connections of the devices to the controller, allowing the system to be handled safe and simplifying the programming of its operation.

MODULE DESIGN

In order to specify the features that the connections module should have, and carry out its physical implementation, a typical assembly cell has been chosen made up of an articulated CRS A255 model five-axis robot, allowing interconnection with 16 inputs and 16 outputs of the cell.

In general, the functions to be carried out by the system can be represented by means of the block diagram in Fig. 1, showing the different elements of the module and the connection flows between the inputs and outputs of both the robot controller and the cell.

As detailed in the block diagram, the treatment of the signals that originate from the controller and the cell are slightly different, although in both cases there is a separating stage isolating the said signals. For example, an input to the controller that comes from a sensor will be filtered by a pulse generator before going through the separating stage, in order to maintain the input for sufficient time for the controller to receive it and consequently proceed. If, on the other hand, an order needs to be sent to any cell actuator, the signal will

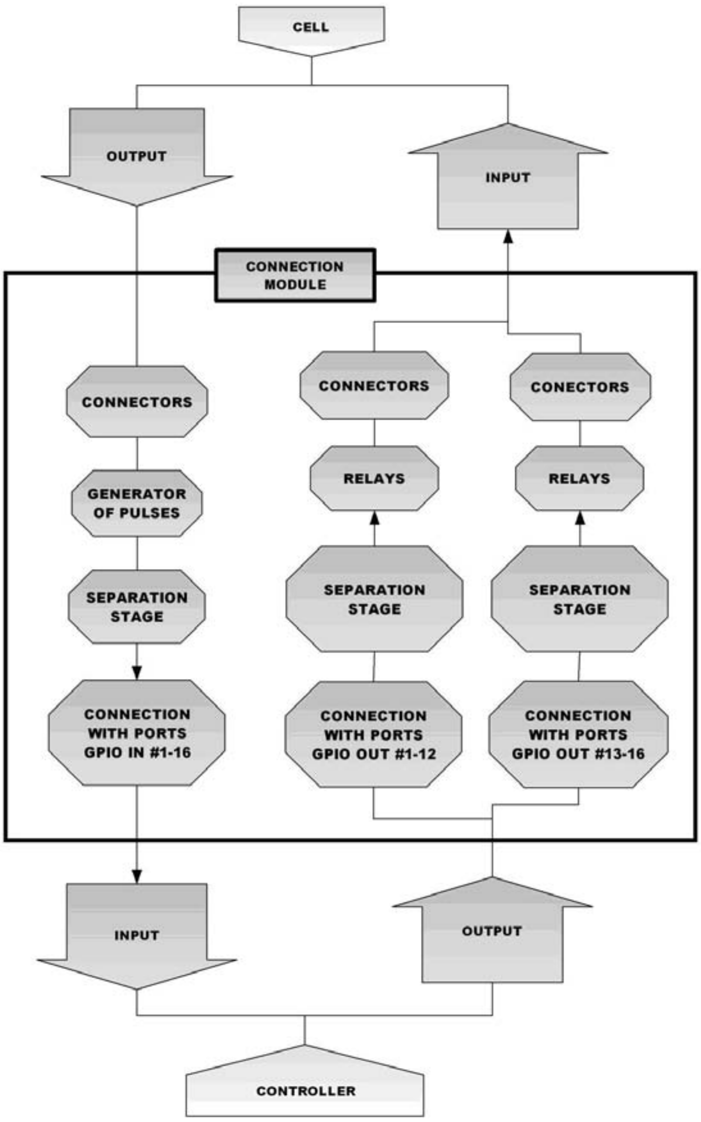


Fig. 1. Connections module block diagram.

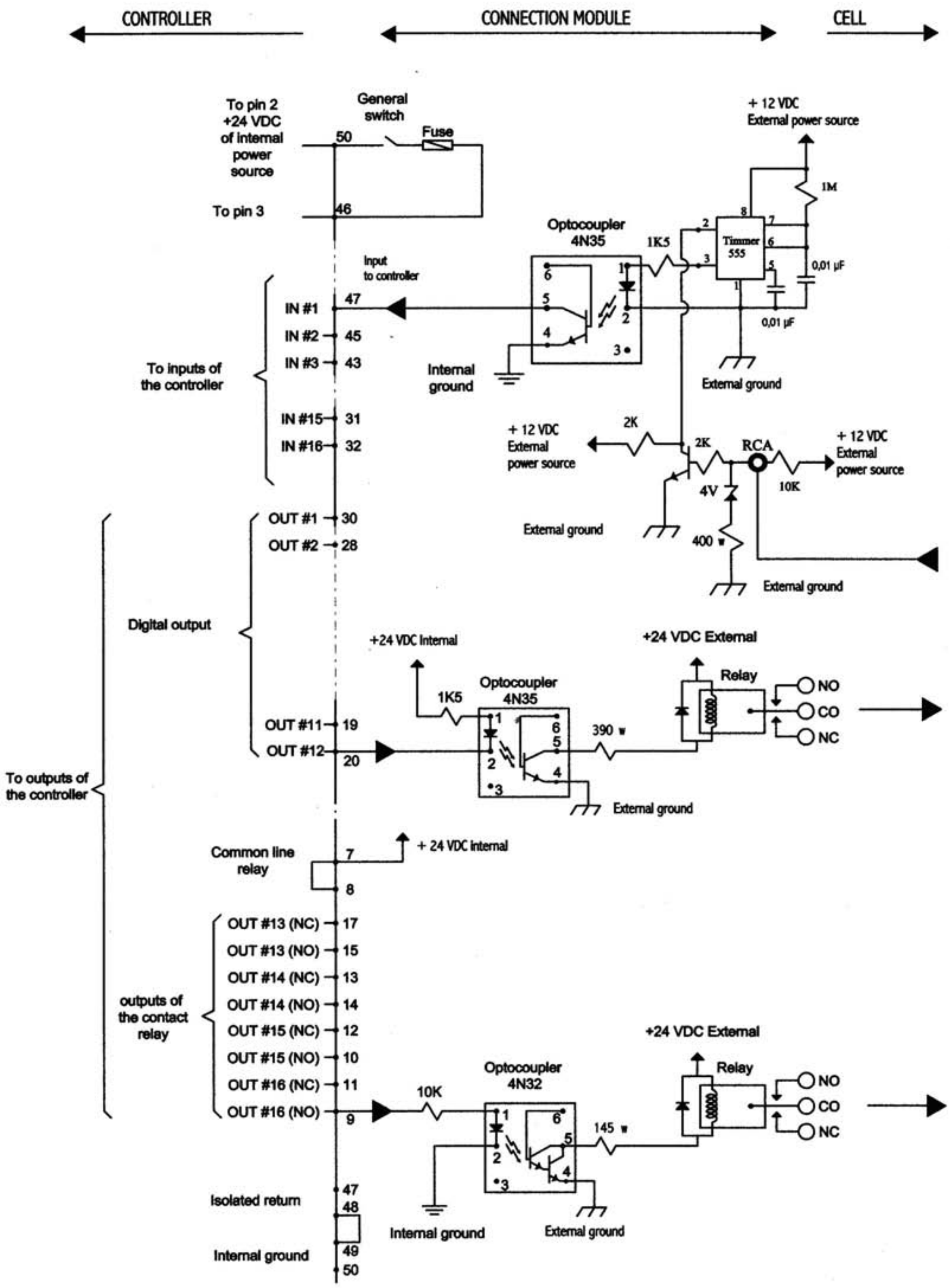


Fig. 2. General electric diagram of the connections module.

be isolated by an optocoupled stage and the actuator will then be operated by means of a contact relay.

Specifically, the functional characteristics of the electronic circuits integrating the module blocks are as follows.

- *Input circuits to the controller*. This will allow the safe connection of the cell sensors to the controller inputs. Additionally, these circuits should ensure the transmission of any cell signal to the controller, no matter how brief its duration. For this, it has been planned that the inputs to the controller go through a pulse generator guaranteeing the minimum time for the arriving signal to reach the controller.
- *Output circuits from the controller*. This will allow the isolated and safe connection of all the controller outputs to cell terminal elements such as the actuators. For this, the controller

outputs are isolated from the cell by means of an optocoupled stage of the module, which operates a series of relays supplied by an external 24 V power supply; thus, the controller outputs are completely separated from the cell, which also makes the connection of power elements possible when necessary.

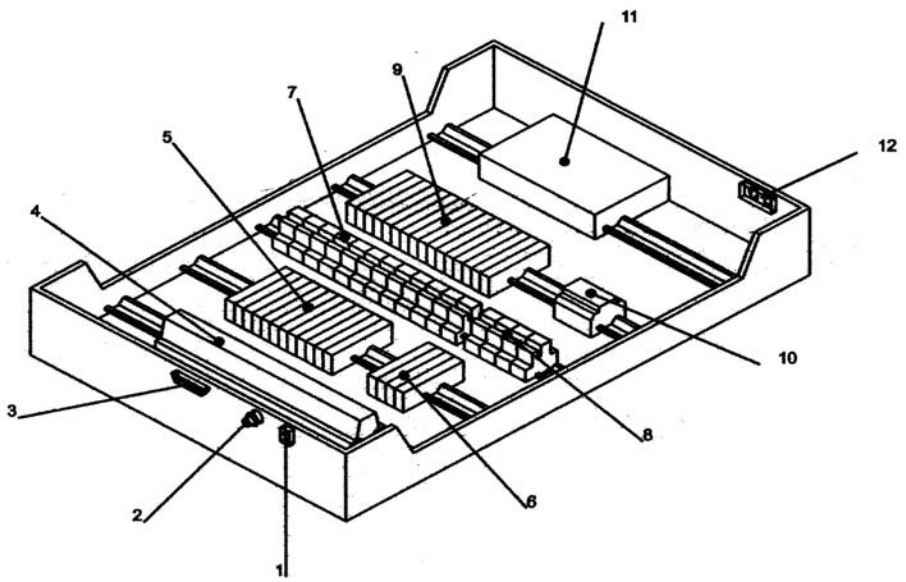
- *Protection circuits*. The connections module should be protected in the event of electricity power failure, surge or contact residual current, by means of a complete safety system. It will include a main switch, quick-trip fuses, residual current circuit breaker and emergency stop switch, guaranteeing the safe operation of the entire system.

Finally, we should highlight that in order to make its use in teaching easier, the connections system of the different cell elements has been simplified and rationalised (sizes, colours, abbreviated names, etc.) and, thanks to its modular design, the detection and repair of the module components in the event of failure is easier.

Figure 2 shows the general electronic connections diagram with the input and output circuits, supplies and returns, both of the internal and external supply, and the correspondence between the module pins and the controller connector pins.

CONNECTIONS MODULE

In order to produce the connections module prototype a plastic box corresponding to a Class II protection switchboard has been used. The components have been placed inside the box on tracks for improved circuit insulation and safety. The external power supply has been installed away from and isolated from the electronic components. On the other hand, the various circuit cables have been joined to the connectors using electric terminals for easier connection and disconnection. In the same way, all the integrated circuits have been mounted on plinths to facilitate their replacement. Figure 3 shows a diagram of the inside of the box



NUMBER	COMPONENTS
1	General switch
2	Fuse of general protection
3	Connector of 50 pins to connect module and controller
4	Terminals to connect inputs, outputs and power supply
5	Output circuits for relay with low electric current (number #1 to #12)
6	Output circuits for contact relay with 3 amperes (number #13 to #16)
7	Relays for relay output with low electric current (number #1 to #12)
8	Relays for contact relay output with 3 amperes (number #13 to #16)
9	Input circuits
10	Differential for external power source of 24 V
11	External power source of 24 V
12	Switch and electric current for external power source

Fig. 3. Layout of the components inside the module.

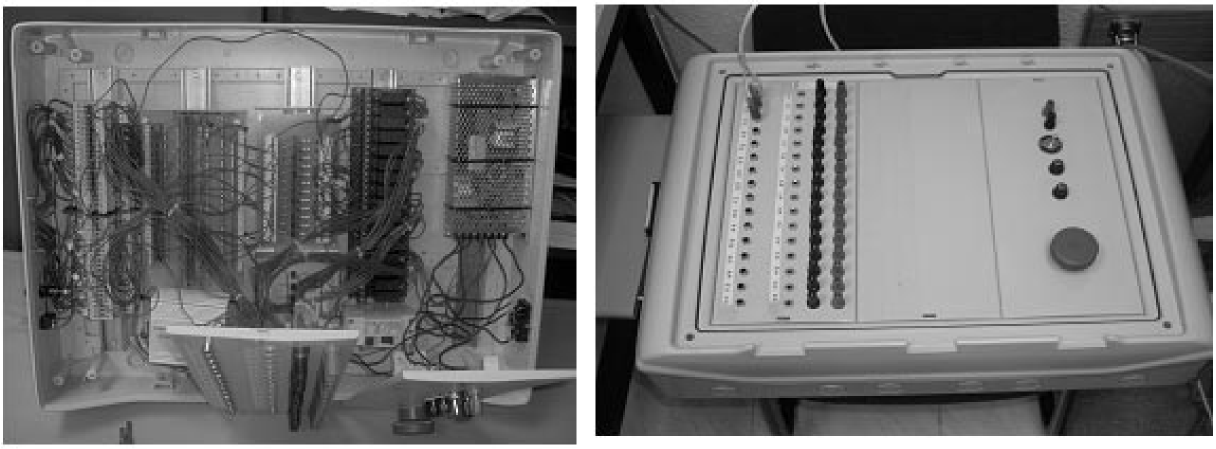


Fig. 4. Connections and components (a), and view (b) of the module.

Fig. 5. Robot arm, digital viewer and micrometers in supports for the module tests.

with the designation and distribution of the components used.

The inside of the module is covered with three adjoining independent lids that are easily dismounted or removed, allowing the carrying out of repairs or replacement operations of the components on the inside. The module has a folding door that allows one to hide and protect the components installed in the outside lids.

Figure 4(a) includes the connections and location of the components installed in the inside of the module. Figure 4(b) shows an outside view of the module with the location of the banana-type output connectors and the RCA input connectors, the protection push button, the fuses and the module main switch.

MODULE TESTS

Once the assembly of the prototype was completed, different tests and partial trials were carried out in order to verify the correct operation of the module components. In order to check the adaptation of the connections module to high-precision automatic assemblies, a test was carried out with the A255 robot arm programmed to carry out high speed, very demanding repeatability cycles (Fig. 5).

The robot gripper moves in a continuous trajectory monitored at various passing points by a pair of micrometers (precision ± 0.1 μm); the separation can be changed with precision. A resin tool has been assembled on the gripper to allow a mechanical feeler (resolution 0.1 μm and precision ± 0.25 μm) to be safely held. The distance between the micrometers was regulated by a minimum value corresponding to the sphere on the end of the feeler. In the different cycles the distance that existed between them was gradually changed as well as the speed and robot acceleration parameters. According to the value of these parameters, the feeler sphere might or might not be in contact with the micrometers.

Given the working speed of the robot, the contact time of the feeler with the micrometers is minimal (less than 20 ms). These data are registered by a digital viewer connected to the mechanical feeler by means of an RS-232 port. This short output signal from the feeler is insufficient to be detected by the robot controller (reads the input port every 20 ms). However, when the signal is sent from the viewer to the connections module, it is able to maintain the signal for a sufficiently long time for the controller to detect it, (specifically the module input circuit is able to detect signals of 5 μs and maintain them for 100 ms).

To verify these data, the IT programme controlling the robot work cycles was provided with a procedure to detect the signal and supply a recognition output. When the feeler comes into contact with any of the micrometers, the viewer sends a signal to the controller by means of the connections module and the programme registers it as a binary signal (in this case, one). Additionally, in order to inform on the contact produced, the programme sends an output signal that, by means of the connections module, activates a light source

Five sets of ten tests were carried out with different acceleration values, speed and distance between the micrometers. In all the cases the coincidence between that indicated by the digital viewer and the light output activated by the connections module was checked.

TEACHING APPLICATION OF THE MODULE

The practical teaching of industrial robotics requires very costly and delicate equipment, made up of robots and controllers, making it difficult for many students to use it simultaneously and independently. Additionally, if this equipment is not suitably used it could cause injury to a student or damage the robot or controller [11, 12].

In order to reduce or eliminate these drawbacks, over the past few years there have been a series of teaching experiments with virtual laboratories in order to teach robotics that, taking advantage of the new communication technologies (internet, systems remote operation, virtual reality, etc.), allow students to carry out practical exercises without any risk and from any location such as their home, library, etc. [13–20].

However, although the said methods can be suitable for the teaching of robotics at a basic level, in-depth and above all more professional learning requires a real knowledge of the robotic cells and a direct contact with its components (robot arm, controller, programmer, input and output devices, etc.). For this reason, the training of technicians specialised in industrial robotics should be approached in a realistic and practical way (with direct access to the programming, connection between devices, selection of input and output signals, etc.) to supplement the virtual learning.

For this purpose, in the industrial robotic courses taught at the Polytechnic University of Madrid designed to train specialised technicians, a real practice session with a cell is included. The practice session consists of making an adhesive joint to be fixed to a cover of a part. Relative humidity and temperature are the relevant parameters for the assembly process that uses structural acrylic adhesives and these should be kept within certain margins. On the other hand, the objective is that once a fixture is concluded, the controller emits an electric signal to a panel, lighting up a red bulb. The students have to draft the design and connections of two inputs to the controller in order

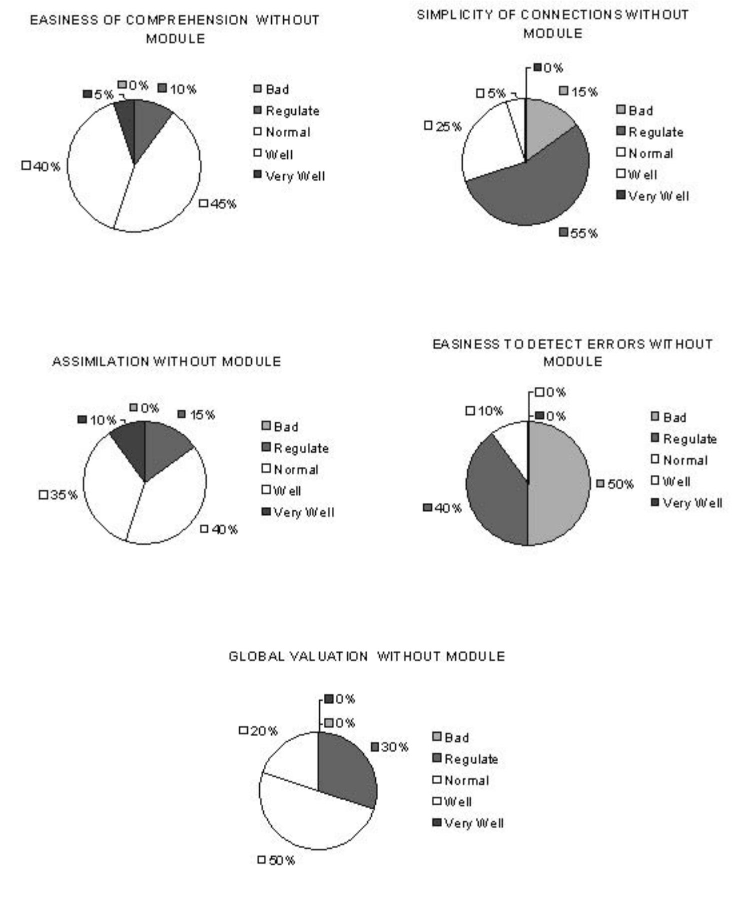


Fig. 6. Results of the questionnaires of the students who did not use the connections module in their practice session.

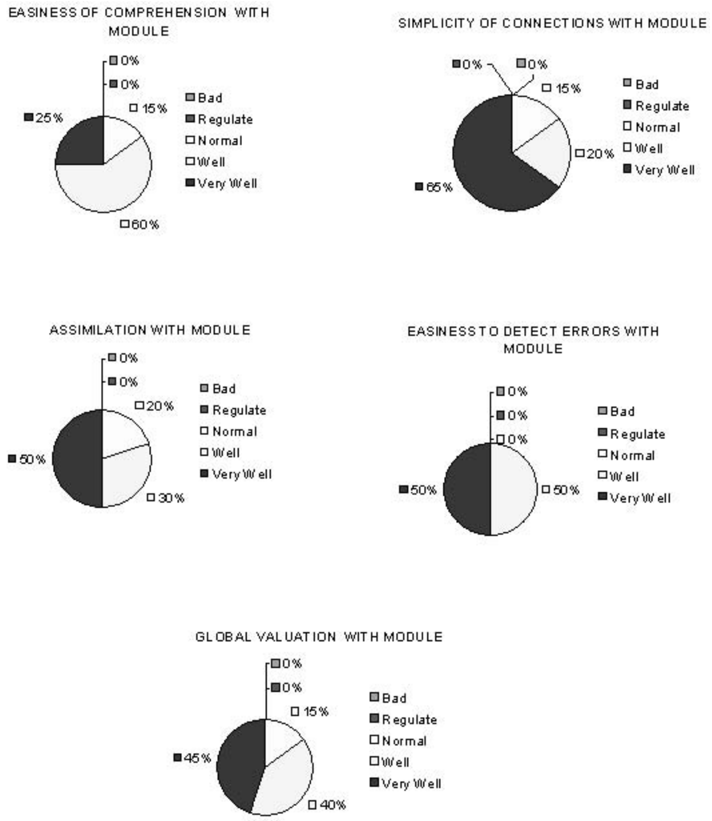


Fig. 7. Results of the questionnaires of the students who used the connections module in their practice session.

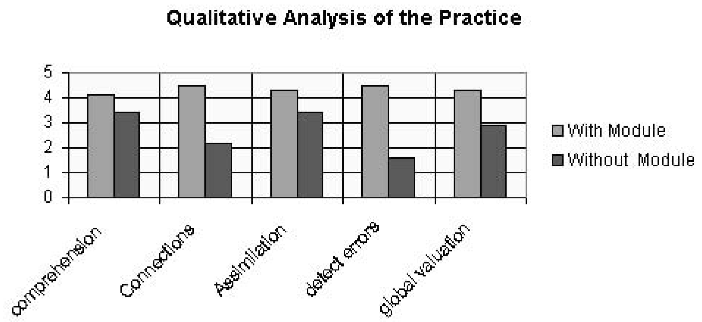


Fig. 8. Comparative analysis of the teaching with the connections module.

to send temperature and relative humidity sensor signals in such a way that when the acceptable margins are exceeded or a push button is operated, the controller stops the joining process. Additionally, the students have to design and carry out an output connection of the controller to light up the red bulb in a panel as soon as the adhesive joint is completed.

The input and output connections systems of the robots are usually complex and do not provide suitable protection systems. When the students carried out this practice session and made mistakes the controller protections were sometimes damaged.

For this purpose, the use of the input and output module described in this document was proposed for these practice sessions. In order to analyse the suitability of the module an assessment of the results obtained when compared with the previous system was carried out.

The students were divided into twenty groups of two students for the analysis. Half of the groups used the new module and the other half the other system. The study had a double aspect: on the one hand, and with a qualitative nature, the students were asked about the learning characteristics (comprehension, simplicity of connection, degree of satisfaction, etc.) and on the other, with a quantitative nature, the time used in the carrying out of the connections and the number of mistakes made were noted.

The quantitative analysis included a student questionnaire measuring the degree of satisfaction with the practice session based on the following criteria: ease of comprehension, simplicity when

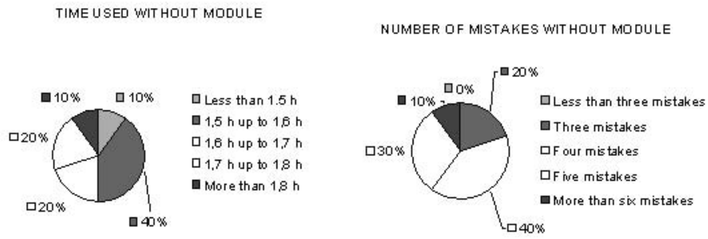


Fig. 9. Results of the quantitative analysis for the students who did not use the connections module in their practice session.

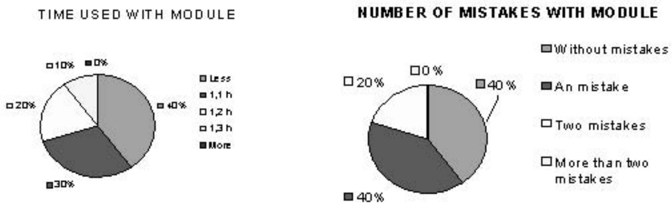


Fig. 10. Results of the quantitative analysis for the students who used the connections module in their practice session.

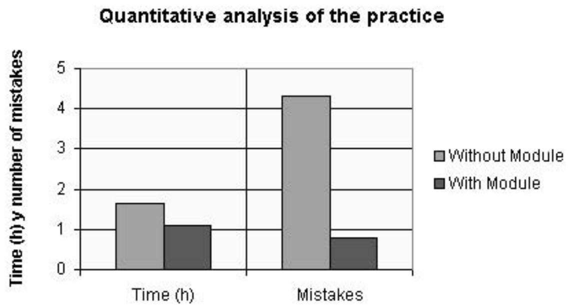


Fig. 11. Comparative analyses of the times and errors with the connections module.

carrying out the connections, assimilation of the contents, ease of error detection and global valuation of the practice. The students had to value each criterion with points, between 0 and a maximum of 5 points. Figure 6 includes the results obtained from the questionnaires of those students who did not use the new connections module. The graphics show that although there is sufficient general evaluation, there are serious deficiencies with respect to the simplicity of carrying out the connections and error detection (with percentages of dissatisfied students of 70% and 90% respectively). Figure 7 includes the results obtained from the questionnaires of the students who used the connections module. The graphics show a very wide general satisfaction (above 80%) and an outstanding improvement in the simplicity of the connections and error detection (percentages above 80% of satisfied students).

Figure 8 shows a comparative graphic analysis of both systems. Average values have been taken as reference elements for each qualitative criterion. The results show a higher degree of satisfaction from the students who had the connections module, both for each individual criterion and for global valuation.

In the quantitative analysis two factors were measured: the time taken by the students carrying out the connections and the number of mistakes made. Figure 9 includes the results obtained in the measurement of the quantitative factors for the students who did not use the new connections module. The graphics show that for 60% of the students the time taken in the practice session was between 1.5 and 1.7 hours. Additionally, more than 80% of the students made more than three connection mistakes. Figure 10 includes the results obtained from the measurement of the quantitative factors for the students who used the connections module. The graphics show that more than 70% of the students took less than 1.3 hours in the practice session. Additionally, an outstanding decrease in the number of errors can be seen (80% of the students made less than two errors).

Table 1. Percentage and absolute improvement obtained using the connections module

	Comparative of teaching with the module of connections						
	Qualitative					**Quantitative**	
	Comprehension	**Connections**	**Assimilation**	**Detect** errors	**Global valuation**	**Time** (h)	**Mistakes**
With module	4.1	4.5	4.3	4.5	4.3	1.1	0.8
Without module	3.4	2.2	3.4	1.6	2.9	1.65	4.3
Difference	0.7	2.3	0.9	2.9	1.4	–0.55	–3.5
Percentage	20.59	104.55	26.47	181.25	48.28	–33.33	–81.39

Figure 11 includes a comparative graphic analysis of both systems. Average values have been taken into account as reference elements of each quantitative factor. The results obtained show that the students who have a connections module take less time in completing the practice session and make fewer mistakes.

Therefore, we can see that the designed connections module improves the industrial robotics practice sessions teaching process both at a qualitative and quantitative level. Table 1 includes the improvements (in percentage and absolute terms) obtained using the connections module for each of the qualitative criteria and quantitative factors considered.

CONCLUSIONS

Although the virtual robotic laboratories can be suitable for the teaching of robotics at a basic level, in-depth and above all more professional learning requires a real knowledge of the robotic cells and a direct contact with the components of the same (robot arm, controller, programmer, input and output devices, etc.). For this reason, the training of technicians specialised in industrial robotics should have a realistic practical approach (with direct access to the programming, connection between devices, selection of input and output signals, etc.) to supplement the virtual learning.

In order to improve this practical teaching, a prototype of a functional module for the connection of inputs and outputs was designed and manufactured. The connections module developed improves the performance of the cell in precision assembly operations as it simplifies the robot communication with the peripheral sensors, facilitates a quick adaptation to the changes required by the cell and rationalises the methodology for the connections. Additionally, it allows the cell to control the very-short duration signals (5 μs) and guarantees an integral protection of the controller as it is electrically isolated from the input and outputs.

The results in the use of the connections module as an aid at third-cycle university level teaching on assembly cells with robots show a considerable teaching improvement, both at a qualitative level (with teaching satisfaction of more than 45%), and quantitative level (with a considerable decrease in completion time and number of errors). Therefore, the module developed enables the student to comprehend clearly the multiple connections of the devices to the controller, allowing a safe handling of the system and simplifying the programming of its operation.

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