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DEVELOPMENT AND CONTROL OF A PROTOTYPE TYPE SCARA AND GANTRY APPLIED TO EDUCATIONAL ROBOTICS

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Abstract: *This paper presents the development and manufacture of a robot manipulator SCARA type with five degrees of freedom, and a Cartesian robot type Gantry, applied to the educational field, whose methodology will employ the goal of accounting, functionality and optimization costs. The prototype SCARA presents an innovation over traditional fixed-base manipulators modifying this structure to develop horizontal linear motion, which will provide a greater extent of workload, minimizing a present limitation of these machines. The Gantry system will be idealized with the possibility of positioning in three axes of movement, two horizontals perpendiculars to each other, and other vertical to which can be added an effector any the fixing base, and may function as 3D printer, rapid prototyping printed circuit boards, among others. The trajectory control systems of the machines are of the continuous type, using stepper motors with microstepping drive in open loop. The manipulators have gone through stages of development and experimental testing of their mechanical systems, interface circuits, embedded systems and programming, in order to explore all the speed characteristics and repeatability of positioning.*

Keywords: *prototype, low cost, microstepping, education, manipulators.*

1. INTRODUCTION

Within the vast field of robotic systems, devices called manipulators stand out for being used to move objects around. These machines find applications in different fields of industry, where they work as material handling, welding, spray painting, among others.

In 1950 General Mills Corporation (USA) developed the gantry-robot system, which is a manipulator with linear movement. Gantry type robots have great potential for applications in mechanical metal industries in the sector, mainly because of its rigid structure, its ample work space and ease of programming from the dynamic decoupling between the movements of your links (Menuzzi et al., 2010). Cartesian systems for printed circuit fabrication using tools that cut the surface of the plate leaving only the desired paths. Similarly, the 3D printer is used to manufacture end products when demand is low and it is not economically feasible to build a whole assembly line. These machines also have relatively unviable costs for the acquisition and maintenance, preventing its use by designers and amateurs. The proposed gantry system is low cost and easy assembly. Some authors have proposed similar positioning systems such as Menuzzi et al. (2010); Duarte Neto, Oliveira and Riul (2009); Lacerda, Balduino Filho and Siqueira (2005); Oliveira (2013); Lucas, Dutra and Bonacorso (2012).

Created in 1979 at the University of Yamanashi, Japan, the SCARA robot (Selective Compliance Assembly Robot Arm) was developed to meet a specific demand of the industry, but become popular, no longer a special configuration (Stone and Kurfess, 2005). Often the operation to locate and manipulate to stock, to park and store certain object can cause inconveniences such as defects or damage due to packaging, content violations, losses or exchanges, becoming a common problem in passenger terminals, libraries, guard volumes, parking lots, trading stocks, among others. The SCARA prototype on a small scale it is a solution for handling and storage of stocks. Some authors have studied this type of manipulator, such as Bittencourt et al. (2013); Battistella, Pieri and Stemmer (1999); Padoin, Odair and Valdiero (2010).

Given the constant search for improvements in teaching methodology, it is increasing the need for improvement in education techniques, one of the most efficient ways, the union of theory and practice. According to Rothe-Neves, Silva and Barreiros (2004), the use of didactic prototypes in teaching and research is crucial both to stimulate students, how to direct teachers to not limit education to common methods, such as: board, Project and simulations, that only with the theory, could hinder the understanding and hide problems in real systems. In this context, robotics has great potential as an interdisciplinary tool, since the construction of prototypes generally makes the student question and be able to relate different knowledge and skills in order to solve a problem (Celinski et al., 2012). Recently, several studies have proposed robotic systems low cost whit educational applicability, such as Cocota et al. (2014); Silva, Barreto and Lemos (2012); Santos, Birth and Bezerra (2010); Medeiros Filho and Gonçalves (2008).

The proposed objective it is mechanical design, instrumentation and control position in open architecture, a SCARA type robot manipulator with four degrees of freedom for positioning and a degree related to the effector type gripper, with applicability in inventory organization, and a gantry type robot with three degrees of freedom, with applicability in the manufacture of printed circuits. It is proposed as a technological contribution based on a modification of the SCARA, which will no longer be set for linearly horizontally move, increasing the effector workspace. The prototypes must have an affordable cost, robustness and flexibility to meet diverse topics for study since its didactic applicability (programming, position control and speed, sensors/actuators, manufacturing integration, data communication, design of machine elements, etc.). Mechanical structures based materials will be reused defined, open architecture and software drivers, and low-cost drives.

2. PROTOTYPES DEVELOPMENT

The SCARA type robot is traditionally provided with a fixed base followed by two rotary joints, one prismatic and, in some models, one rotary joint orientation, as shown in Fig. (1a). These devices are adapted for vertical approach, which makes them agile in moving objects and to have good speed and accuracy, they are widely used in precise assemblies involving large number of items, such as electronic circuits (Padoin, 2011). However, their workload is limited to $4\pi L^3$, where L is the length of each link. The proposed structural model promotes a movement of the base in order to increase the working space, thus constituting four degrees of freedom for positioning as shown in Fig. (1b). The fifth grade corresponds to the gripper, which will be designed to attend the need to transport materials with flat side surfaces. The Gantry robot is considered the most robust type of manipulator. It has simpler kinematics among the most common types of industrial robots due to use of three prismatic joints and, in some cases, a rotary joint for orientation of the effector end (robotic gripper or tool) (Menuzzi et al., 2010). The Fig. (1c) shows the mechanical structure of a Cartesian gantry type system.

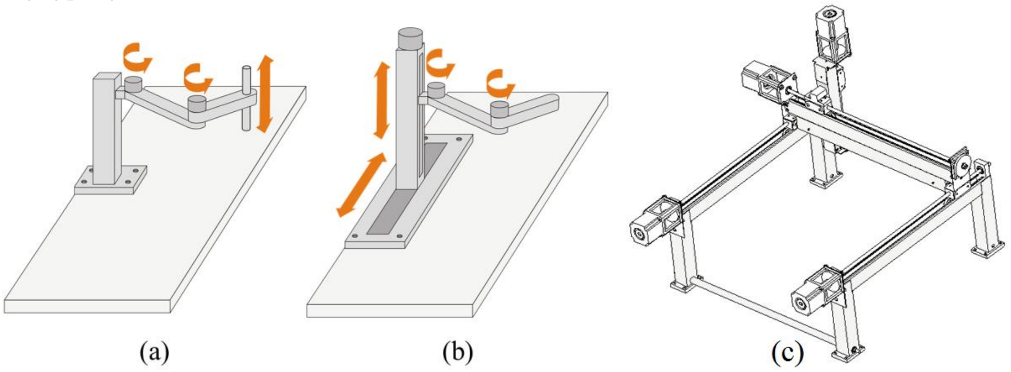

Figure 1. Mechanical assembly: (a) traditional SCARA, (b) SCARA extended and (c) gantry.

Position control with stepper motors can be implemented by setting the number of transmitted pulses. The speed is controlled by the frequency of these pulses. The fact that the magnitude of the pitch angle to be constant causes the motor to be very useful in applications related to positioning, since the operation if it gives in the motor operating limits, it is not necessary to monitor the position of its axis every moment, which characterizes its control as open loop (Barreto, 2005). For a manipulator develop their work accurately and repeatability is necessary and suitable mechanism and drive, has an effective control system (Padoin, 2011). In addition to the stepper motor itself, it is necessary for its operation called an electronic device driver (Barreto, 2005), which controls the switching of the current, which may reach several amps from logic signals (pulses) received as input. In the microstep mode of operation, the natural pitch angle of an engine can be divided into many smaller angles through the current control flowing through each winding, which causes a component of the resultant magnetic field according to a trigonometric model. The use of a current limiting circuit which turn on and off the voltages in the phases is known as pulse with width modulation or modulation width pulse (PWM), which makes the current to flow around the desired nominal value (Barreto, 2005). The action on and off the tension became known as “chopping”. Advanced Controllers of stepper motors may use modulation of pulse width to realize microsteps, thereby obtaining a higher position resolution and smoother operation. In Fig. (2) presents the block diagram proposed for the firing of each degree of freedom which operates in the positioning of the manipulators.

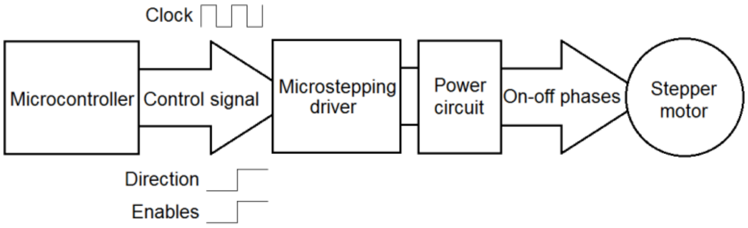

Figure 2. Block diagram proposed for the stepper motor drive with microstep operation.

The control strategy using the voltage applied to mow stepper motors is recent, and caused them to begin to be used in a wide range of applications in robotics and industrial automation, once reserved for DC servomotors much higher cost (Segenreich e Vargas, 2000). A control architecture is an abstraction of a range of agents such as: the number of structural components where the activation occurs and use of sensors; the specification and functionality of each interface component, the interconnection topology between components, among others. The system with closed architecture, the robot is a “black box”, where the interface and actions are known, but not the implementation. In open systems, all machine details are well documented and all aspects of machine design may be modified.

3. STRUCTURAL ROBOT SCARA ASSEMBLY AND PROGRAMMING

The manipulator has a designed based XY axes driven independently by 9,9Kgf.cm stepper motors and transmission pulley/belt systems. In linear basis, it was coupled an articulated arm with two joints triggered by 5,5Kgf.cm stepper motors. The articulated arm is mounted in the horizontal plane and so any influence of gravitational force can be disregarded. The gripper is driven by servomotors type S3003. The whole assembly is controlled by an embedded system composed of commercial microcontroller and drivers.

3.1 Mechanical Assembly

The mechanism consists XY base (308 mm extension in the X axis and 218 mm on the Y axis), mounted with linear ball guides, the transmission system of aluminum GT2-20 type pulleys and toothed belt GT2/6mm. Square aluminum profiles 100mm were used to house the linear guides and square profiles 60mm outside used to support the entire set. The coupled robotic arm is manufactured with links 60mm aluminum profiles and machined aluminum joints, where the engines are coupled. The mechanical drive system was mounted looking for the best fit and adjust for setting both the first connect averaging parts and avoid the belt slippage adjustments thereof in their respective pulleys engines. Parts such as bearings, bearing support and voltage regulators of belts, both were machined nylon and aluminum seeking to diversify the materials used in order to show the student the possibility of lighter weight materials in the manufacture of the robot. In Fig. (3) it is shown the mechanic system mounted.

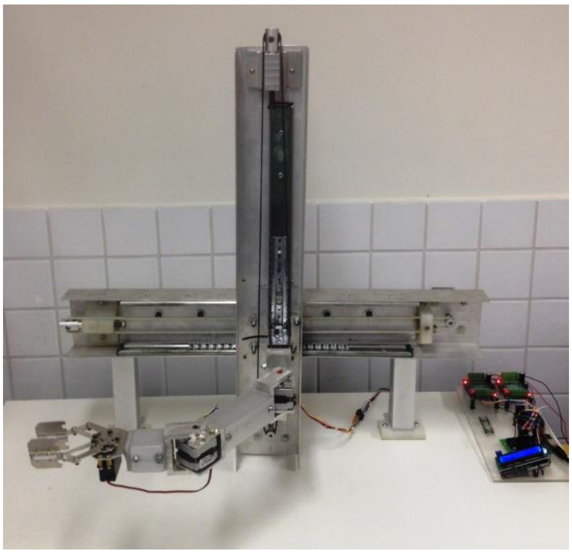

Figure 3. Mechanic system SCARA extended.

3.2 Embedded System and Human Machine Interface

The embedded system is composed of software and basic hardware with PIC18F4550 and USB interface. The set is an open architecture and efficient tool, without the need for microcontroller removal for the firmware update. The recording software is executable and automatically recognized by the operating system without the need for driver installation (bootloader). The system has input for external source with regulator 7805, and uses the Communications Devices Class (CDC), which emulates a virtual RS-232 port via USB 2.0 channel. The system has the number of 13 Analog/Digital converters (10 bits) and uses an external crystal oscillator of 20MHz to generate the frequency of 48MHz USB communication through frequency multiplier prescaler. The system may have HMI interface distance by Bluetooth JY-MCU SLAVE HC-04 modem set to 19200bps. There are nine analog outputs for sending control signals to the motors, and the task of screening is performed through mini keyboard and displayed on I2C 16x2 LCD display. For the movement of the XY axes are used KP35/9HM2 standard NEMA 23 stepper motors, controlled by numerical control programming interface with control option the distance by Bluetooth. The motors are powered by Toshiba BL-TB6560-V2 drivers in unipolar connection with individual 3A consumption. The motor control uses the external control pin EN+, CW+ and CLK+ driver. The pin EN+ enables system operation at low logic level, and disables the engine at a high level. The CW+ pin at low level enables the system to turn to the anti-clockwise direction and at a high level clockwise. To determine the speed of movement of the axes, we used a PWM control signal at the CLK+ pin with variable pulse width and number of pulses calculated for position control. The control board has microstep 1/8, enabling a resolution of 0,225º that used for the engine corresponds to 1600 pulses for a complete turn. In Fig. (4a) presents the embedded system mounted.

The prototype of the operation to the user is simple, objective and autonomous and developed in language C/C++, requiring the entry code of the object to be located, generated in storage. The machine is scheduled to start position and waiting task in zero-point machine. The man machine interface (HMI) presents on display, options regarding the storage operations or location of the object, to be chosen by keyboard or remotely by Bluetooth device (cell phone software, for example). The set of absolute positions in coded cell is checked for empty space to new storage (there is communication capacity) or location object already stored. In Fig. (4b) the flow chart of programming is displayed.

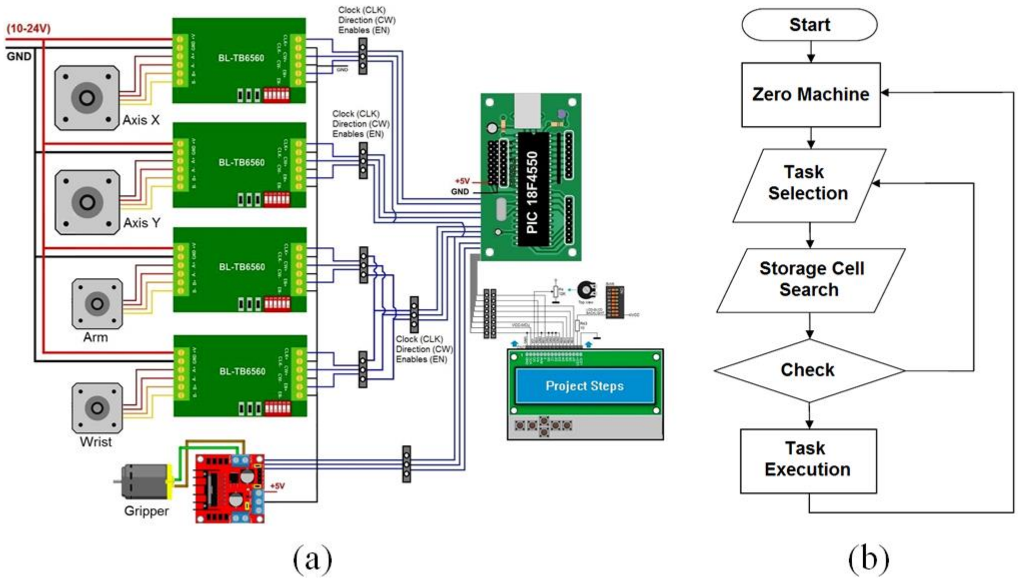

Figure 4. SCARA system: (a) Schematic of the control system, (b) Functional operation flowchart (HMI).

3.3 Experimental Results

For performance evaluation has been performed a set of 10 samples for the drive system (all of its degrees of freedom) to the coordinate space that represent the location of storage cells (x; y; z). For simplification, the z coordinate will not be addressed to represent the whole gripper robot arm retreated into the machine zero point, or in its advanced every point, which is the location of storage cells in the magazine format with positions (x; y). For a better understanding of the analysis, the results were separated into horizontal movements (x) and vertical (y) to be observed performance repeatability of positioning and speed of the degrees of freedom in these directions set separately, however, to be understood the assembly is positioned on both movements simultaneously. In this regard, the horizontal position storage cells were tested for 304mm, 203mm and 101mm, and the vertical positions of 218mm were, 145mm and 73mm. That is, the positions of the cells are studied: (304; 0), (203; 0), (101; 0), (0; 218), (0; 145), (0; 73) (304;

218), (304; 145), (304; 73), (203; 218), (203; 145), (203; 73), (101; 218), (101; 145) and (101; 73) related fifteen storage cells. The Tab. (1) shows the data collected for the horizontal and vertical coordinates individually.

Table 1. Experimental data for the horizontal and vertical coordinates individually.

	Horizontal Positions						Vertical Positions					
	304mm		203mm		101mm		218mm		145mm		73mm	
Sample	Pulse	mm/s	Pulse	mm/s	Pulse	mm/s	Pulse	mm/s	Pulse	mm/s	Pulse	mm/s
1	12244	62	8084	63	4149	60,8	1078	101	715	101	368	99
2	12245	62	8084	63	4149	60,8	1078	101	717	101	365	100
3	12244	62	8084	63	4149	60,8	1079	101	717	101	365	100
4	12245	62	8084	63	4149	60,8	1079	101	717	101	366	100
5	12244	62	8084	63	4149	60,8	1070	102	714	101	366	100
6	12245	62	8084	63	4149	60,8	1079	101	715	101	366	100
7	12244	62	8084	63	4149	60,8	1071	102	715	101	365	100
8	12245	62	8084	63	4149	60,8	1071	102	715	101	370	99
9	12244	62	8084	63	4149	60,8	1071	102	717	101	366	100
10	12245	62	8084	63	4149	60,8	1071	102	717	101	366	100

Taking as reference the limit switch sensors positioned at coordinates (x; y), and by means of programming, they computed the number of pulses for the positioning of all the samples in order to observe the control repeatability and was calculated set speed to reach the final position. The set presented good accuracy for all measured coordinates with axes running individually and together, with a maximum error of about 1% to positioning coordinates (304; 73). The resolution of the set is 0,2 mm and average speed (in magnitude) to 141,9mm/s, equivalent to a shift between more distant storage cells in 4,9s.

4. STRUCTURAL ROBOT GANTRY ASSEMBLY AND PROGRAMMING

The manipulator has designed and built an XYZ basis with each driven shaft independently by 9,9 Kgf.cm stepper motors and transmission spindles. The whole assembly is controlled by an embedded system composed of commercial microcontroller and drivers.

4.1 Mechanical Assembly

The projected XYZ manipulator has a base with each axis driven independently, but synchronized via control. The positioning is accomplished by step motors of 9,9 Kgf.cm and transmission spindles. The whole assembly is controlled by an embedded system composed of commercial microcontroller and drivers. The mechanism base XYZ is mounted on guides aluminum profiles 60mm, stainless steel spindle drive system with 8mm in diameter and 1,25 mm pitch. The X and Y axis stroke is 500 mm and the Z axis is 250 mm. Square aluminum profiles 60mm were used to support the whole assembly. A mini rectifies be used for cutting printed circuit boards. In Fig. (5) is shown the mechanical system mounted.

Figure 5. Mechanics Gantry prototype.

4.2 Embedded System and Human Machine Interface

The embedded system is composed of software and basic hardware with PIC18F4550 and USB interface. The set is an open architecture and efficient tool, without the need for microcontroller removal for the firmware update. The recording software is executable and automatically recognized by the operating system without the need for driver installation (bootloader). The system has input for external source with regulator 7805, and uses the Communications Devices Class (CDC), which emulates a virtual RS-232 port via USB 2.0 channel. The system has the number of 13 Analog/Digital converters (10 bits) and uses an external crystal oscillator of 20MHz to generate the frequency of 48MHz USB communication through frequency multiplier prescaler. The system may have HMI interface distance by Bluetooth JY-MCU SLAVE HC-04 modem set to 19200bps. There are nine analog outputs for sending control signals to the motors, and the task of screening is performed through mini keyboard and displayed on I2C 16x2 LCD display. For the movement of the XYZ axes are used KP35/9HM2 standard NEMA 23 stepper motors, controlled by numerical control programming interface with control option the distance by Bluetooth. The motors are powered by Toshiba BL-TB6560-V2 drivers in unipolar connection with individual 3A consumption. The motor control uses the external control pin EN+, CW+ and CLK+ driver. The pin EN+ enables system operation at low logic level, and disables the engine at a high level. The CW+ pin at low level enables the system to turn to the anti-clockwise direction and at a high level clockwise. To determine the speed of movement of the axes, we used a PWM control signal at the CLK+ pin with variable pulse width and number of pulses calculated for position control. The control board has microstep 1/8, enabling a resolution of 0,225º that used for the engine corresponds to 1600 pulses for a complete turn. In Fig. (6a) presents the schematic of the embedded system.

The prototype of the operation to the user is simple, objective, autonomous and developed in language C/C++, requiring the programming provided the trajectories for making a printed circuit board. The machine is programmed for starting position in zero-point machine, and start cutting tool should be positioned at zero-piece position in manual mode via keyboard or remote device via Bluetooth (phone into software, example). The man machine interface (HMI) presents display in the possibility of system configuration, access schedules, motion tracking and other features. In Fig. (6b) the machine operation flowchart for working printed circuit prototyping is displayed.

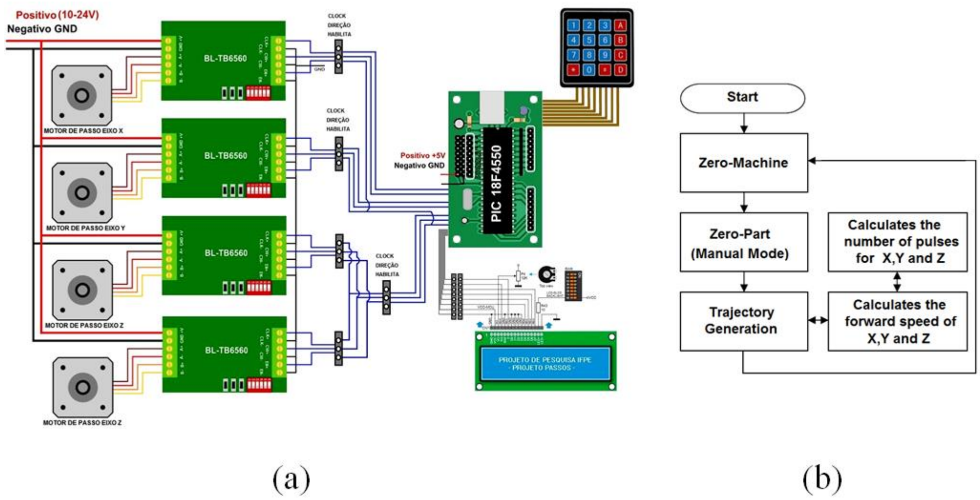

Figure 6. Gantry system: (a) Schematic of the control system, (b) Functional operation flowchart (HMI).

4.3 Experimental Results

To evaluate the performance it performed a set of 10 samples for the drive system to coordinates in space that represent linear trajectories (x; y; z). For simplification, the z-axis position control will not be covered because it represents the movement of going up and down the tool for cutting printed circuit board, with the coordinates (x; y) the trajectory this tool. For a better understanding of the analysis, the results were separated into horizontal motion (x) and vertical (y) to be observed positioning repeatability and speed in these directions separately, however, it should be understood that the assembly is positioned in both movements simultaneously, with a linear relationship between the axes. For the coordinates of the x-axis, they were tested to 487,0mm, 324,6mm and 162,3mm, and the y-axis coordinates were 435,0mm, 290,0mm and 145,0mm. That is, the linear paths are studied: (487,0; 0), (324,6; 0), (162,3; 0), (0; 435,0), (0; 290,0), (0; 145,0), (487,0; 435,0), (487,0; 290,0), (487,0; 145,0), (324,6; 435,0), (324,6 ; 290,0) (324,6; 145,0), (162,3; 435,0) (162,3; 290,0) and (162,3; 145.0) related fifteen trajectories. The set showed good accuracy for all the coordinated measures with axes running individually and in sync by a linear relationship. If a maximum error position observed from about 0,2% to a starting point (0; 0) moving in a linear trajectory to the end point (324,6; 145,0) [mm]. The other coordinates had lower positioning errors, so that for use in manufacturing of printed circuits, which have trajectories with smaller distances, the system presents good performance. The other coordinates had lower positioning errors, so that for use in manufacturing of printed circuits, which have trajectories with smaller distances, the system presents good performance. The resolution of the set is 0,001 mm and maximum forward speed (in magnitude) is 5,19mm/s. The Tab. (2) shows the data collected for the horizontal and vertical coordinates individually.

Table 2. Experimental data for the horizontal and vertical coordinates individually.

	x-axis coordinate						y-axis coordinate					
	162,3 mm		324,6 mm		487,0 mm		145,0mm		290,0 mm		435,0 mm	
Sample	Pulses	mm/s	Pulses	mm/s	Pulses	mm/s	Pulses	mm/s	Pulses	mm/s	Pulses	mm/s
1	116448	3,56	303610	2,73	487042	2,55	97586	3,79	261852	2,83	433376	2,56
2	116668	3,55	304051	2,73	486823	2,55	97586	3,79	261852	2,83	433376	2,56
3	116668	3,55	304429	2,72	487042	2,55	98025	3,78	261852	2,83	433375	2,56
4	116668	3,55	303109	2,73	487043	2,55	97805	3,78	261852	2,83	433376	2,56
5	116448	3,56	303109	2,73	487042	2,55	98025	3,78	261852	2,83	433375	2,56
6	116668	3,55	303109	2,73	487263	2,55	97806	3,78	261852	2,83	433595	2,56
7	116448	3,56	303109	2,73	487263	2,55	98025	3,78	261852	2,83	433376	2,56
8	116448	3,56	303329	2,73	487263	2,55	98025	3,78	261852	2,83	433375	2,56
9	116668	3,55	304270	2,72	487263	2,55	98025	3,78	261852	2,83	433376	2,56
10	116668	3,55	304270	2,72	486823	2,55	98025	3,78	261852	2,83	433596	2,56

5. CONCLUSIONS

This paper presents the development of the mechanical structure, instrumentation and position control in open architecture embedded in a prototype manipulator SCARA with five degrees of freedom, applied to the organization of stocks, and prototype manipulator Gantry with three degrees freedom, validated for prototyping circuit.

The prototype SCARA presented satisfactory results regarding the extent of the workload, the mechanical strength, the manufacturing costs and the effectiveness of the HMI interface. The machine drive system was mounted looking for the best fit and adjust for regulating both the first connect averaging belt pieces as well as adjustment and avoid slipping on pulleys of the same respective motors. The ball linear guides are shown favorable to the displacement of the XY axes not favor unnecessary clearances to be movements avoiding the rocking effect on the terminal of the robotic arm. The machine had maximum positioning error of 1% and an average speed of 141,9mm/s representing good results for the application, because the optimum repeatability. The prototype SCARA was estimated at $317,58 with embedded system mounted for $106,94 mechanical assembly for $191,20 and other costs related to consumables and accessories.

The prototype Gantry showed satisfactory results in terms of mechanical strength, the manufacturing costs and the effectiveness of the HMI interface. The set for zone proved to be conducive to the displacement of the XYZ axes showing no gaps that would generate positioning errors. The mechanism presented a maximum error of 0,2% at the maximum stroke position, so that for use in the manufacture of printed circuits, which have trajectories with smaller distances, the system displays an even better performance. The resolution of the assembly is 0,001 mm and the maximum speed of the tool advance (in magnitude) is 5,19mm/s, which is appropriate for circuit printing. The prototype Gantry was estimated at $294,2 with embedded system set up by $166,0 and mechanical assembly for $187,46 and other costs related to consumables and accessories.

The use of low cost materials was favorable for the educational purpose of the project, as ratified the initial idea of mobility of mechanicals robots components. The assembly of mechanical components was carried out, mostly, by bolts, washers and nuts, facilitating the assembly and disassembly of the equipment in order for a pedagogic demonstration of manufacture and assembly of the robots.

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