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Proposal of Educational Low Cost Robotic Arm with Spindle Drive

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***Abstract* — This article presents the construction of a low cost robotic arm with spindle drive for its movement controlled using PIC microcontroller. The objetive of this study is to present a viable alternative and with a short production time, ideal for educational activities when used in introduction for robotics.**

***Keywords* — Low cost; Robotic Arm; Spindle Drive.**

I. INTRODUCTION

One of the most promising areas in technological advance nowadays is robotics, where is rare not to find practical applications in various everyday activities across the world.

With the technology broadcasted in the society, it is ìndispensable for the growth of anyone the contact with this kind of technology, but, considering that often it's complex and also experimental, the costs to obtain the necessary tools for educational learning might be expressive, many times making it impossible to get in certain regions.

And before these appointments presented, it was developed a robotic arm, with a lower cost and easy to make.

II. OBJECTIVE

This document represent a proposal for a robotic arm focused on educational learning with four degrees of freedom, whose activation will be based upon the microcontroller PIC 16F877A. This prototype, in turn, has the purpose of being used as a introductory mean to the user in the world of robotics since its first assembly. The usage of spindle drive for horizontal displacement has as objective increasing the easiness of application and needs lesser torque from the electrical motors than other methods, and then reducing costs and production time.

III. THEORETICAL FOUNDATION

A. Robotic Arm

The concept of robotic arm is a mechanism capable of simulating all the movement conditions that a human arm can make, considering all kinds of movement.

For these movements to be possible, the arm must contain the same components as the human arm has, being them: *links* (which represents fingers, forearm, and arm), *joints* (knuckles, wrist, elbow and shoulder).

The relationship between two links and one joint of this mechanism will constitute one degree of freedom, as show in the Figure 1.

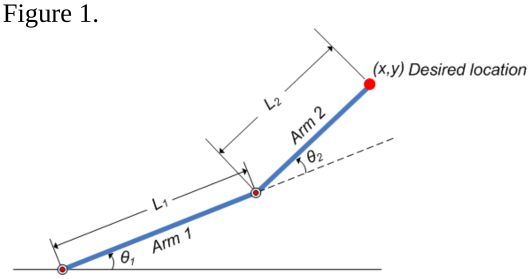

Figure I – Degree of Freedom

For a robotic arm to become near a human arm, it must contain seven degrees of freedom, being these: Pitch, yaw and roll for the shoulder, pitch for the elbow, and pitch, yaw and roll for the wrist. The robotic arm is capable of realizing considerable movements with just three degrees of freedom, but it must be known that the work envelope will be limited [1].

Each link has an angle θ of movement and a length of L which is being transferred to the same angle related to the axis analyzed. The sum of all moving parts in a robotic arm will constitute the end effector pose of this arm, represented by ξE.

The equation below represents the direct kinematics of the actuator according to the quantity of joints and links available in one determined robot.

E = R(θ1)*T(L1)*R(θ2)*T(L2)*R(θn)*T(Ln), where:

E > End effector pose

R = Angle rotation

T = Motion translation

The result of this equation will be a homogeous transformation matrix, which in the end will give a position in the X and Y axis to the end effector.

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$$\begin{pmatrix} x_o \\ y_o \\ 1 \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta & x_f \\ \sin\theta & \cos\theta & y_f \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ y_1 \\ 1 \end{pmatrix}$$

With the result of the end effector pose in hands, it is possible to initiate the control of the robotic arm for it to develop the desired movement.

B. Direct Current Motor

The DC motors are devices that operate using the attraction and repulsion forces generated by eletromagnets and permanent magnets. And its force depends, basically, on the voltage applied to coil, which will determine the circulating current, and consequently, creating a magnetic field strength.

This type of motor is a machine destinated to transform electrical energy into mechanical energy, and beyond that, it also needs a source of direct current. It can work with adjustable velocity between broad limits and, normally, are used to control of great flexibility and precision in adjusting its velocity, having its use restricted to special cases in which these requirements compensate the higher cost of installation.

C. Spindle Drive

The spindle drive is a mechanical device for linear movement indispensable in the modern industry, which can be used in industries as aerospace, military, pharmaceutical, steel, beverage, mining, automotive, construction, machining and food, being responsible for converting the rotational energy (which can be generated by a DC motor, a stepper-motor or a servomotor), into linear movement.

D. Microcontroller

The microcontroller is an electronic device that has a bundle of elements in its composition, all of these integrated into a single chip, and has the objective of manipulating signals or input data, so that through a set of instructions grouped into a single file or multiple files can activate and/or control the outputs to various applications. Among the elements included, there's the CPU (*Central Processing Unit*), where the programs are processed, the clock system, which can trigger the CPU activities, the memories that store instruction and data, and the input and outputs, which allow the interaction with other signal sources.

IV. METHODOLOGY

The methodology applied to the prototype development was the model PDCA, which consists in four steps, being the following: *Plan*, *Do*, *Check* e *Act*.

During the Plan phase, it was defined the usage of two servomotors and two DC motors, with spindle drive to allow the angular movement of the links number two and three of the robotic arm. It was also defined the usage of plastic as main structural material to support the structure itself and the motors, and the drivers to control the motors.

The purchase of the components, such as: motors, drivers and a kilogram of PLA plastic, was performed during the Do phase of the method, and after that, during the Check phase, the PVC plastic was used as replacement to the 3D printing process in the initial prototyping, to validate if the idea was proper to the project.

Given this, the last phase of the method consists in the Act of prototyping, which included the 3D printing of all pieces, doing the assembly and concluding the process.

V. PROJECT DEVELOPMENT

A. Mechanical Components

For didactic purposes, it was proposed the development of a robotic arm having four degrees of freedom being capable of realize movements similar to an industrial robotic manipulator. The material chosen to compose the pieces at the final project was the PLA plastic, due to its properties of mechanical resistance and density, providing a low weight and demanding lesser torque from the motors to its movement.

The first prototype was developed with the objective of assessing the operation of the spindle drive movement being activated by dc motors. The material chosen for this first prototype was PVC, due to its resemblance to the PLA, easy deformation of the material to obtain the pieces in the determined sizes and for fixing it was used kits of bolts and nuts at size M3, as shown in the Figure II.

Figure II – Pre prototype

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During prototyping, it was noticed that the usage of spindle drive to execute the angular motion in the links number two and three would reduce the cost of the motors, and for that, two spindles were used, being one of 7.5mm and other of 4.7mm of diameter and their length are 172 e 130 mm, respectively. Both spindles use the whitworth thread and are attached to the motor axis with a coupler.

The tests demonstrated that the vibration on the thread caused destabilization on the motor, due to a connection failure between the spindle and the axis of the motor, and after adjustment, it was able to observe the functionality of the initial prototype and prove its efficience in relation to the movement of all degrees of freedom equally. It's important to emphasize that it was noticed that the use of spindle drive impacted on the travel time from one point to another, showing that it was slower than other type of systems, but the choice of using spindle drive was kept (Figure 3 below) due to the reduction on the torque needed for the motors, and with that, the cost reduction on these, beyond the easiness of coupling and attaching the spindles to the motors.

Figure III – Spindles

Before the development of the second prototype, it was developed a computational simulation of a model based on the first prototype using the CAD software SolidWorks to test possible changes on the arm, in order to improve the efficiency as shown in the figure IV.

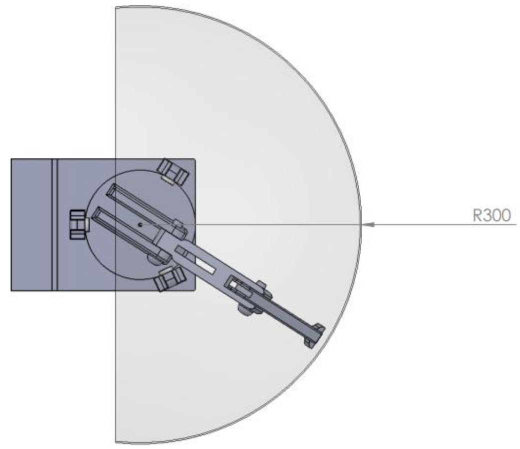

Figure IV – Computational model in SolidWorks

For the development of the second prototype, the method chosen was 3D printing (Figure V) of the pieces that makes up the arm, due to the production speed and better cost-benefit ratio when compared to traditional methods of machining. The computational model developed on SolidWorks was selected after tests that showed effectiveness and significative reduction on the system destabilization.

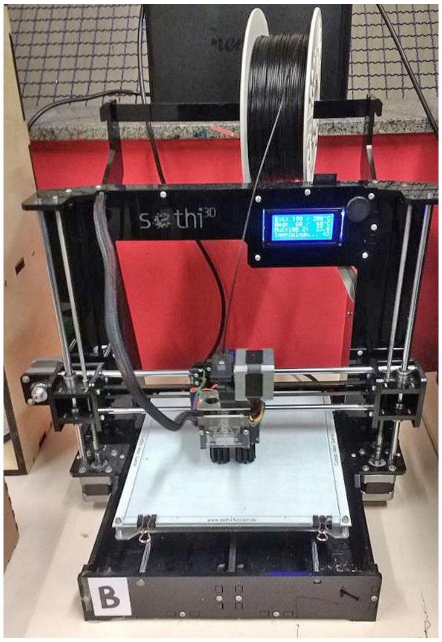

Figure V– Final prototyping of the pieces

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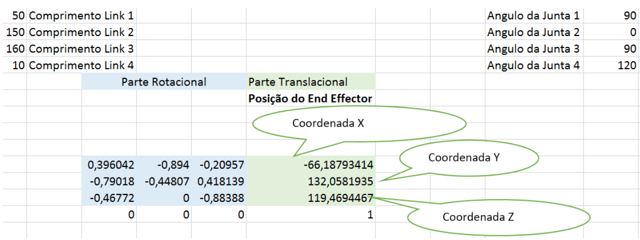
After 3d printing, the prototype was assembled and the motors fixated on its structure, making the robotic arm ready to use.

With the arm ready, the modeling of the system was made through MatLab, using the engine Robotics ToolBox, and the equation generated was transported to Excel in order to make it easier to visualize the position of the end effector in the axis X,Y and Z, and the forward kinematics of the robotic arm determine that, considering the initial pose for the robot, the end effector must be positioned in the coordinates shown in the Figure VI (in milimeters).



50	Comprimento Link 1			Angulo da Junta 1	90
150	Comprimento Link 2			Angulo da Junta 2	0
160	Comprimento Link 3			Angulo da Junta 3	90
10	Comprimento Link 4			Angulo da Junta 4	120
	Parte Rotacional		Parte Translacional		
			Posição do End Effector		
0,396042	-0,894	-0,20957	-66,18793414		
-0,79018	-0,44807	0,418139	132,0581935		
-0,46772	0	-0,88388	119,4694467		
0	0	0	1		

Figure VI – Forward kinematics modeling

B. Electronic Components.

To control the robotic arm, it was chosen the microcontroller PIC16F877A, which has the needed characteristics to be implemented on the system.

To generate the needed current for the DC motors, the circuit described in the Figure VII was created, using LM2577 as a regulator and a module with the H bridge was used for each motor. For the two servomotors, the PWM signal was connected directly into the microcontroller and the power wires were connected directly into the DC source of the circuit.

A fiberglass pcb was used to accomodate the circuit shown in the Figure VII, using the heat transfer printing method to create it.

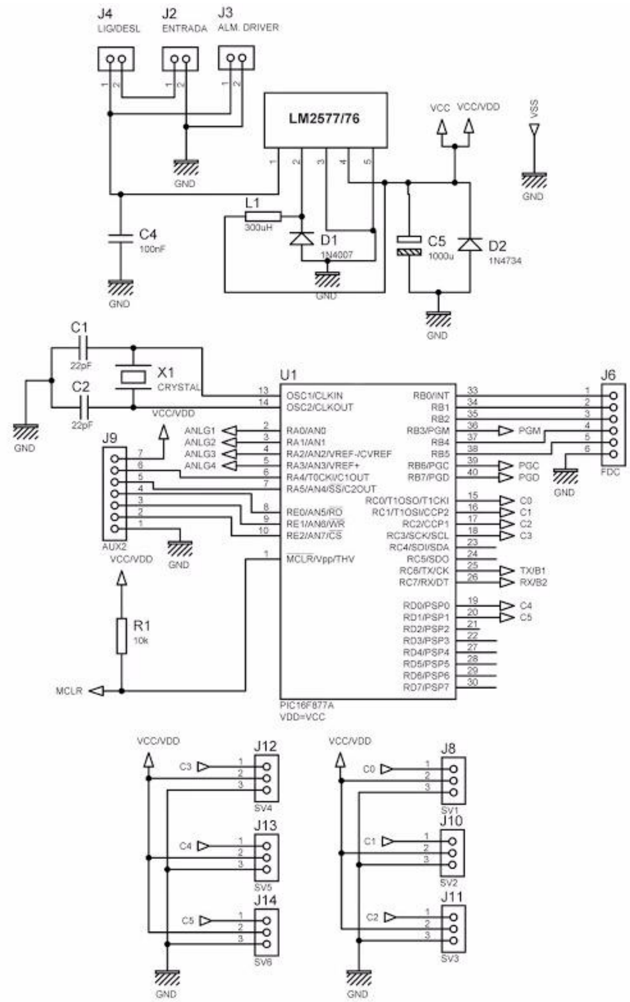


Figure VII– Electronic circuit diagram

To limit the angle of the workspace, microswitches were used in both DC motors. Those switches are not necessary when using the other two servomotors, because it's already angle limited.

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On the control interface, two joysticks were added to move the degrees of freedom of the arm, and thinking about the safety of the people around the prototype, one emergency button was added, in case that all of the control functions need to be disabled. For that, it's needed to press the red button available on the joystick interface and then, any and all action of the robot will be blocked, generating a sound warning to get the operator's attention.

And below the control system of the arm is shown. In the Figure VIII, it's possible to see the diagram with all the flows during control, from beggining to end.

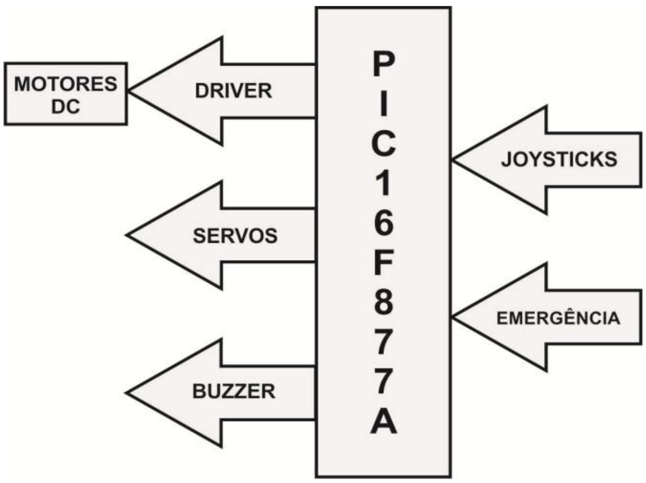

Figure VIII– Control system diagram

VI. Results

After the development of the final pieces and the assembly of the control with the roobtic arm, a program was added to the PIC microcontroller to test its efficiency and prove the usage for educational purpose, and the prototype has shown promise for such.

Figure IX– Prototype of robotic arm concluded

After the conclusion of the prototype, a survey based on the local market for similar products was conducted to compare the products that are available with the prototype created as shown in the Chart I, and in the end of the survey limited to the city of São Paulo, the average price of a robotic arm kit, considering the structure and the motors was R$430,00. In contrast, the relative costs of the prototype was R$358,00, showing a reduction of 16,5%.

Table 1–
Relation between materials and prices

Qty.	Description	Price (R$)
1	Driver L298	19,90
2	Motor 12V com redução	70,00
1	Servo motor MG995	44,00
1	Microservo SG90	35,00
1	Garra para microservo	14,90
1	Caixa Plastica	7,90
4	Chave fim de curso	2,00
1	Impressão em PLA	165,00

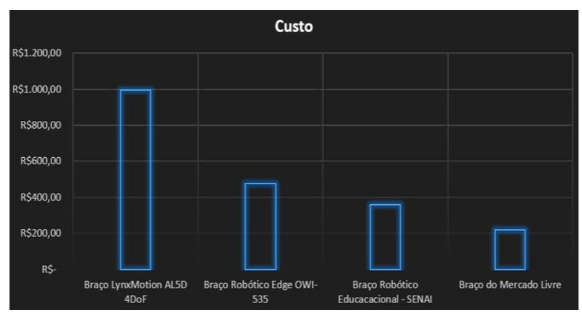

Chart 1– Price comparison

VII. Conclusion

At the end of the project development, a working prototype was obtained costing 16,5% less than similar products available on the market. Value that when considering large-scale production could be even smaller. When opting to use spindle drive, the prototype showed a velocity reduction in the vertical movement due to the spindle properties, however the use of spindle drive demand lesser torque for each motor used.

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