Construction of a low-cost mobile embedded system for computer numerical control and educational purpose

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This article describes the construction of a low-cost, mobile, CNC (Computerized Numerical Command) mini machine, bringing as its objective the gain of experience in relation to machining knowledge, where the device executes a list of movements written in the programming language G. For the development of the project, the Arduino Nano embedded system, two CD / DVD players and two H bridges (L293D) were used. Afterward, the assembly, programming and results of the project in question are described.

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Keywords: CNC Machine, Arduino, L293D, Education, Embedded systems, G-code.

1. Introduction

Before becoming computerized, they were only numerical control machines, an electronic device that directly receives codified instructions through punched cards that had the function of interpreting the generated data to control the gears or pieces of equipment in order to press the designated images [1].

As it is stated on the book *Metal cutting theory and practice*, written by Stephenson and Agapiou [2], the first sample of a numerical control machine was constructed in 1952 in the Massachusetts Institute of Technology (MIT): it was a milling machine, creating continuous movement of tools utilizing aluminium.

New developments were created to promote this technology, the US air force bought many numerical control machines and rented them to corporations, for them to understand the application. In spite of those advancements, there was still the problem in input of instructions, in other words, each manufacturer created their own language solution to indicate the machining processes, generating a dispute among them. Afterwards, the G-code was created by MIT, a programming language developed to bring a certain pattern to the processes, it was quickly adopted by all corporations.

Only on the decade of the 1970s were the computer numerical control(CNC) actually created, as an application of microprocessors and ROM memory to the numerical controllers, increasing it's flexibility, precision and versatility.

Our project aims to report the process of the construction of a low cost, portable computer numerical control to acquire experience and knowledge about machining, related to the creation of complex development of aircrafts, spacecrafts and electronics. The purpose is for the results to be able to be reproduced on schools and educational institutes in order to maximize the learning of students of the area. The utilized embedded system is the Nano Arduino, for it's capacity in dealing with files that executes the

necessary commands to the functioning of the CNC.

2. Bibliographic review

The amount of contributions to this subject is vast, varying in the sense of forms of implementations, materials used and purpose. Following are a few projects that had been done in last few years that were taken as a basis to this project.

Moved by the imperfections of surfboard produced manually and the high cost of a milling machine CNC, which is the device that interprets the code for the equipment to work, the article presented by Gesser et al.[3], which has the objective of creating a low cost solution based on DeskCNC, a software used to determine the steps that the milling machine CNC should take.

The CNC is composed of steel tubes that are adapted to bolted unions, forming the 3 axis (X, Y, Z). That modular structure was assembled to create flexibility and agility on transport, adapting according to the size of the block that is about to be molded.

The software is based on Shape 3D, a program that generates the drawing that the CNC will create. The file is assembled and saved on G format, the programing language common for this kind of application, that the DeskCNC will execute, turning the processes of machining faster and more precise than manual manufacturing, meeting the expectations of the proposed project.

The work done by Dantas and Júnior [4] has the core idea of elaborating a tool to manufacture printed circuit boards to assist on students projects on automation and robotics laboratories situated on the Federal University of Rio Grande do Norte. The researched solution was the construction of a CNC machine that has the capability of executing such a task.

The project has a base constructed from wood, all structured to guarantee that the milling machine does not fall or tremble when the process happens. The movement control is done by a firmware called GRB1, installed on a Uno Arduino. This firmware is free and widely used on the development of CNCs, because of it's high performance on the precision of the machine. After the system is compiled on the microcontroller, it stays ready to receive code written on G language, that posteriorly the BCNC software will send to execute the instructions.

Among the many positives points reported on the development of the project, one to focus on are the tests that were made considering the time of execution of the instructions. There were used 2 different materials as methods of board production: the pen permanently has the time spent on the drawing for around 8 minutes and 47 seconds, however the corrosion time is high (32 minutes and 45 seconds) and because of that, a milling cutter being used is more advantageous, because it doesn't need of corrosion and the time drawing is on average of 17 minutes and 46 seconds.

The cost to realize the project varies at about 465,78 brazilian Reais, which is equivalent to a milling machine CNC distributed on the market, making the solution completely viable.

As it is stated on the article, the project has a few shortcomings in the sense of unevenness of the table and the rails are somewhat loosely, generating precision problems. However even with these, the work done proved it's worth with a good enough precision, reaching the goal designated, being capable of serving as base to articles to come.

The idea proposed by Macêdo et al. [5] is to construct a mobile low cost CNC to amplify the researches on the subject of machining. The base of the project is on the CAD software, which is capable of creating or importing images that were saved on the language G. Posteriorly, the file generated is interpreted by the BCNC software that sends the commands to generate the drawing to a Uno Arduino, who would control the stepper motors according to the pre established model from the code. The project had some problems in it's fabrication, among them the levelling of the table that serves as support to the material that is being modeled and the factor of the electronic components in the sense of isolation and confection. Although it has theses shortcomings, the results proved successful, the precision of the movements were good and it had good handling, maybe even doing more functions besides drawing, such as the example of marquings of certain components.

The total cost of construction of this project was equivalent to 500 brazilian Reais, a very competitive price than a common real CNC. However the disadvantages like degradation of components and the requirement of constant recalibration, but if the objective is only for the creation and exposition on a versatile and playful way, it is possible to develop a machine to match the same results, with less failures and fewer resources.

Finally, the development of two very distinct CNCs, idealized by Lo Valvo [6], focused more on the education side. The first model uses a Raspberry Pi and the second one on a BeagleBone Black, making use of a free software called LinuxCNC that works on ARM architecture that composes the embedded system mentioned.

The price of each complete prototype is around 100 Euros, it's worth noting that each one were used different milling machines, one was acquired named RM Minimill and the other one modified by hobbyists that were used before on an Arduino system.

The raspberry Pi model resulted in some problems because of the few pins it has for the application, generating the necessity of inclusion of extensors devices like the FRDM-KL5Z and put the Arduino CNC Shield on it. Even with the proposed being served, this prototype demonstrated difficulties because of incapacity of the Raspberry Pi with the AXIS graphical interface, massively explored by LinuxCNC, beyond that, the big amount of devices compromised the performance in the end.

The BeagleBone Black prototype was much better, having less devices attached to it, only an adapter for the RM Minimill called bbb_parport. The performance was so impressive that is noted the capability of realizing more angles curves on more surfaces that are detailed.

Even with these findings, the article suffers from the lack of tables and graphic representation of the concrete results of performance, but it manages to reach the proposed idea of increasing the interest of students in the area.

3. Materials and methods

This section has the objective to describe the components and softwares selected for the development of the project, showing its functionalities. On Table 1 it is presented the inventory and the price of each material.

Table 1. Prices of equipment

ITEM	PRICE(USD)
Nano Arduino	$ 8,35
2xL293D	$ 4,29
Micro Servo 9g Sg90 TowerPro	$ 2,86
Jumpers	$ 2,39
Circuit Board	$ 0,48
Fixing screws and hexagon nuts	$ 1,91
Durepox	$ 1,67
Total	$ 21,95

3.1 Arduino

Created in 2005 by the Italian Massimo Banzi in conjunction with a specialized team, with them David Cuartielles, Tom Igoe and Gianluca Martino. The main objective was to bring a low cost free software platform to ease the realization of student's projects who have interest in the field [7].

There is multiple models of the platform to work with, however the one that was chosen for this project is the Nano Arduino, a small board based on ATmega328p, a microcontroller made by Atmel, a manufacturer of semiconductors funded in 1984. The reason for this choice is due to its capacity with dealing with files that executes the necessary commands for the functioning of the machine.

According to Ganssle and Barr [8], the Arduino is an embedded system, having a microprocessor that is totally dedicated to a certain assignment of a device or system that commands it. In other words, it's a system that after receiving a certain number of pre-defined functions, will do them if they're necessary. An example utilizing many times our daily activities is the calculator, it has pre-established requisitions that will only be executed if the user requests.

Through Arduino IDE, which start screen is shown on Figure 1 , where it is reunited the instructions that will be passed to the designated hardware. This software is a multi-platform application written in Java, being derivative of Processing and Wiring [9].
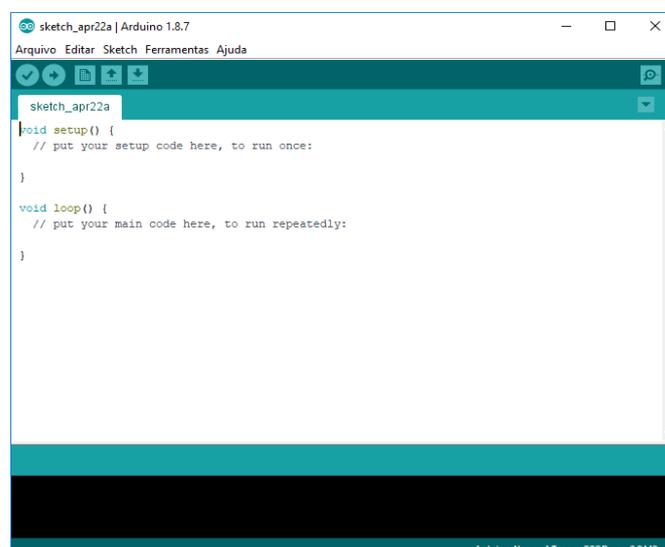

Figure 1. Arduino IDE

The firmware which was written in C will be compiled on the prototype board that was elaborated by Adidax [10], where is contained the necessary instructions that the CNC should follow to do a complete interpretation of the G file.

3.2 H Bridge

It's a circuit that allows the inversion of the motor's polarity. By so, it is necessary a way to load the current on the motor in a direction and another that take to the opposite direction [11]. The H bridge utilized for the creation of the project is the L293D, a integrated circuit that can control motors up to 36 Volts on a constant current of 600mA up to 1.2A [12].

3.3 Motors

There are 2 types of motors that are going to be discussed on this section. The first is the stepper motor shown on Figure 2, a electromechanical device that transforms electric signal into torque, making it spin on a precise manner.
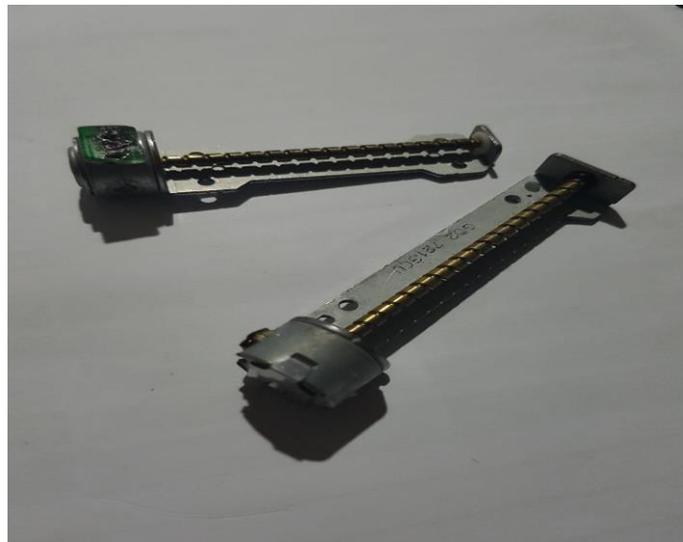

Figure 2. Stepper Motor

The selected stepper motors are contained on CD/DVD drivers, devices that interpret files stored on those formats and transmits their information to other determined device. Two of them were needed for the project, one for the X-axis and the other for the Y-axis. On Table 1 is not shown the price of those equipment's because they were taken from unused broken computers.

The next is a servomotor as displayed on Figure 3, similarly to the previous one is a electromechanical machine that is adjusted to the Z-axis. It works proportionally according to the required command, that is to say, after receiving a signal the servo should go to designated place on a certain speed.

Figure 3. Servomotor.

The model adopted was the Micro Servo 9g Sg90 TowerPro, as it's shown on Figure 3, because of its size and quality and compatibility with the Arduino platform on projects related to robotics. The supply voltage of the servo motor is relatively 5V, being capable of having a variation between 4,5V and 6V, consuming a high current of 200mA to 1A. Normally a servo has 3 ligations wires as it appears on Figure 4, which they are represented by the brown(or black) conductor that has as reference the 0V mass supply, the red being the power supply and the orange(or white) the one that inputs the data commands to the servo.
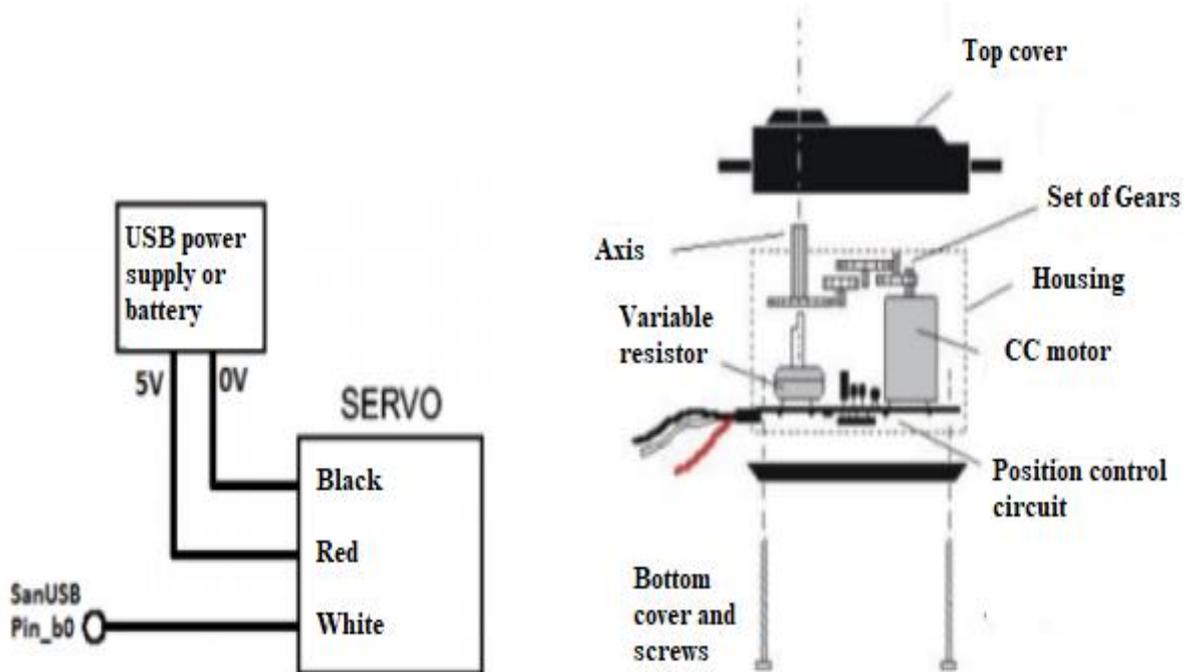

Figure 4. Internal visualization of the servo motor

3.3 Inkscape

Tool used for the construction of vectorial graphics. It has satisfactory portability, by having the

capacity of working on different kinds of operational systems like Windows, Mac OS X and GNU/Linux, for example. Very efficient on the creation of illustrations, logotypes, maps and internet graphics (THE INKSCAPE TEAM, 2003) [13]. This software, which main menu is displayed on Figure 8, will be used for the development of images that the mini CNC will write. Even with this array of utilities, this tool does not have the capacity to generate G files, for that it will be needed the installation of an extension who provides such feature. Created by Mcguire [14], the MakerBot Unicorn G-code library meets these fundamental requirements, however the Inkscape should be on 48.5 version because this extension was not tested on future updates and could trigger some unexpected software bugs

3.4 Processing

Processing was elaborated by Reas and Fry [15], it's a free software language based on graphical functionalities of the Java programming language and has an integrated development environment, designed for the electronic and visual projects communities. It has as its main feature to proportionate basic notions of programming.

On it is executed gctrl, created by Mellis [16], a simple program, whose objective is to send a G format file to the Nano Arduino. As it is shown on Figure 5, this software has some functionalities that will be able to complete this task.

```
INSTRUCTIONS
p: select serial port
1: set speed to 0.001 inches (1 mil) per jog
2: set speed to 0.010 inches (10 mil) per jog
3: set speed to 0.100 inches (100 mil) per jog
arrow keys: jog in x-y plane
page up & page down: jog in z axis
$: display grbl settings
h: go home
0: zero machine (set home to the current location)
g: stream a g-code file
x: stop streaming g-code (this is NOT immediate)
```

Figure 5. Gctrl program layout

The 2 main functions are executed when the "p" key is selected, which establishes the communication between the serial port with the Arduino and the "g" key that will search the image and then send it to the board.

3.5 Circuit and structure

The CNC circuit was constructed using as basis the diagram shown on Figure 6. The H bridges connect themselves to the step motors and the supply power of the Arduino, while the stepper motor communicates only with the supply and the prototyping board.
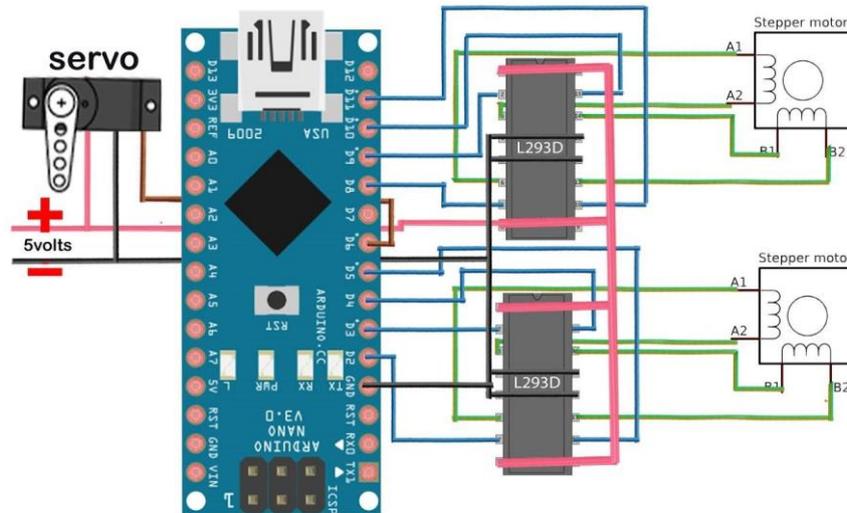
Figure 6. Circuit Diagram [17]

It was constructed on a printed circuit board displayed on Figure 7, where were organized the components according to the size of the board used.
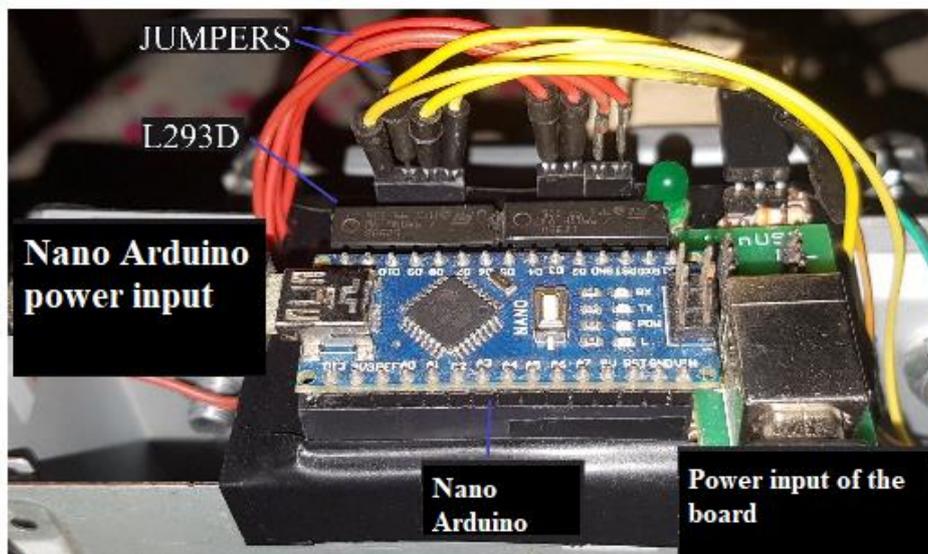

Figure 7. Constructed circuit

To build the base of the CNC, it was used the casings of CD/DVDs drivers, after their stepper motors were removed. As observed on Figure 8, the 2 drivers were placed on such way that formed something similar to the word "L".

Figure 8. CNC skeleton

This type of form allow the fitting of the possible axis, for the alignment of them preventing failures. On figure 9, it is shown the concluded structure.
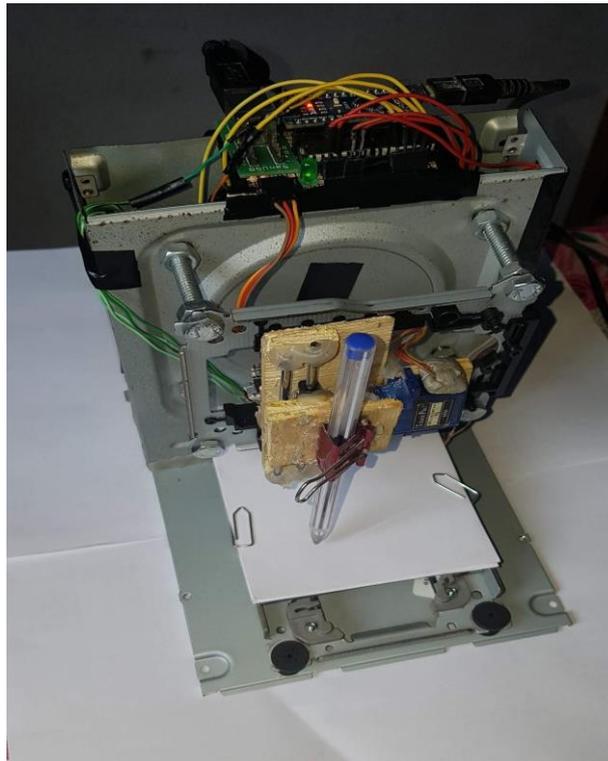

Figure 9. Concluded CNC

3.4 Implemented software

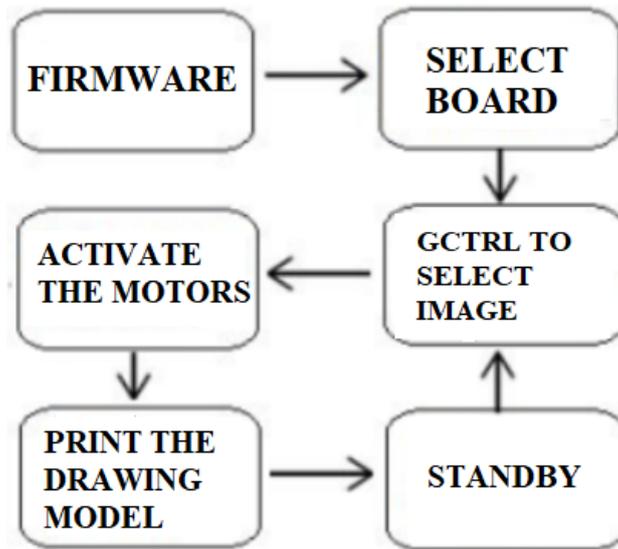The CNC must follow the fluxogram displayed on Figure 10.

Figure 10. Steps of the process

The firmware is saved on the device, through Arduino IDE, then it is selected the determined image on G format, that the board posteriorly sends the necessary commands to activate the CNC's motors, to finally execute the designated task. After the activity is concluded, the software will be waiting for the user to provide a new image.

4. Results

Multiple tests were made, utilizing a bic pen that had the goal of testing the precision and the time taken to realize either a complex or simple drawing. The first analysis was made on a simple drawing, represented on Figure 11, where possible to see the level of details of the results is presented.
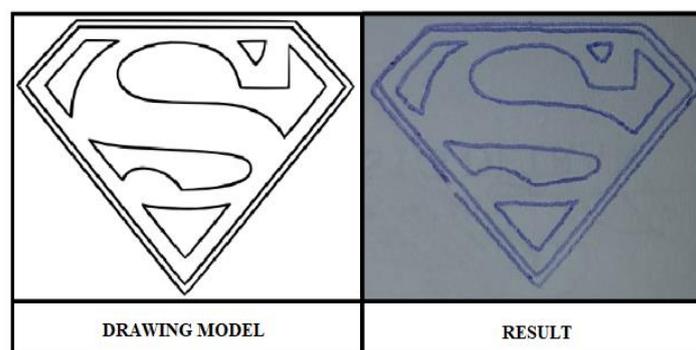

Figure 11. First test

The next test was made on a drawing that required a bigger degree of details and even with the bigger challenge, the efficiency of the CNC proved to be impressive as it is shown of Figure 12.
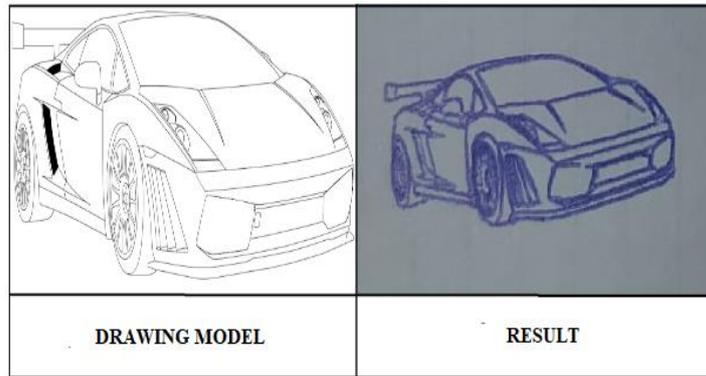
Figure 12. Second test

The third and final test verifies the capability of creating multiple circles. Even though it has some imperfections because of the chosen pen and the size of the drawing, the results displayed on Figure 13 are very satisfactory.
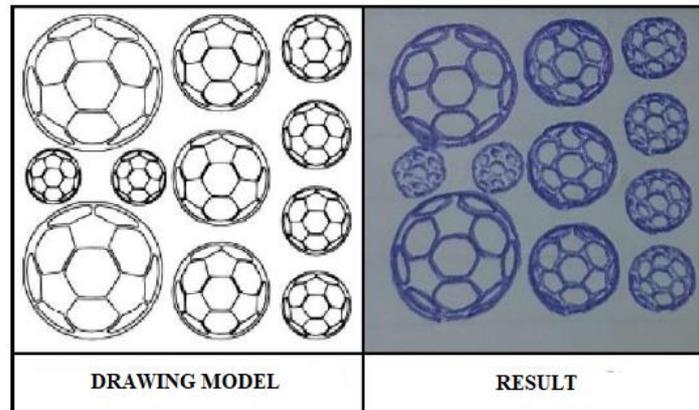

Figure 13. Third test

On Table 2 is organized the results in relation to time of execution.

Table 2. Results

TESTS	TIME
First	41 seconds
Second	5 minutes and 24 seconds
Third	8 minutes e 35 seconds

5. Conclusion

The core idea at the start was to construct a low cost mini CNC with the focus on learning of the processes of machining on a practical versatile way to be able to be reproduced on multiple education

institutes in order the learn this subject. The objective was reached, displaying satisfactory results upon the done executions.

The construction of the CNC lasted around a month, however because of the intricacies of the project and bibliographic review, the total time lasted 4 months. The biggest challenges were the care taken in the sense of compatibility of tools either on the hardware such as motors and microcontroller and on the software side, where each decision affects performance and production.

The total project cost was 21,95 US Dollars, a relatively low price in comparison to the knowledge acquired and performance of the machine. It leaves some improvements to be made by other students like the creation of CNCs that do the markings of pieces of equipments or boards of printed circuits through a more specific milling cutter.

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