Design, Construction & Performance Test of a Computer Numerical Control Machine

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Abstract:

This paper is designed to develop a low cost and flexible device for controlling the Computer Numerical Control machine controller. The purpose of a Computer Numerical Control machine is to facilitate system to a specified computerized control, then to maintain it at that control a controlled manner machining. Using Micro controller PIC- 16F84 is one of the best way for precise control with low cost. We can complete it with the help of PLC (Programmable Logic Controller) but it's too costly with respect to our project. By using the PIC -16F84A Micro controller technology has made it possible, practical and desirable to have the Computer numerical control included in the same instrument that is also controlling the other aspects of the equipment. At the end of the project, a prototype of microcontroller based Computer Numerical Control System will be developed.

1. Introduction:

Computer Numerical Control (CNC) is one in which the function and motion of a machine tool are controlled by means of a prepared program containing coded alphanumeric data. CNC can control the motion of the piece of tool, the input parameter such as feed, depth of cut, speed and functions such as turning spindle on/off, turning coolant on /off.

The design and construction of Computer Numerically controlled (CNC) machines differ greatly from that of conventional machine tools. This difference arises from the requirements of higher performance levels. The CNC machines often employ the various mechatronics elements that have been developed over the years. A Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) program. The part designer uses the CAD/CAM program to generate an output file called a part program. The part program, often written in "G Code," describes the machine steps required to make the desired part. You can also create a G Code program manually. A file transfer medium such as a USB flash drive, floppy disk, or

network link, transfers the output of the CAD/CAM program to a Machine Controller. [1][2]
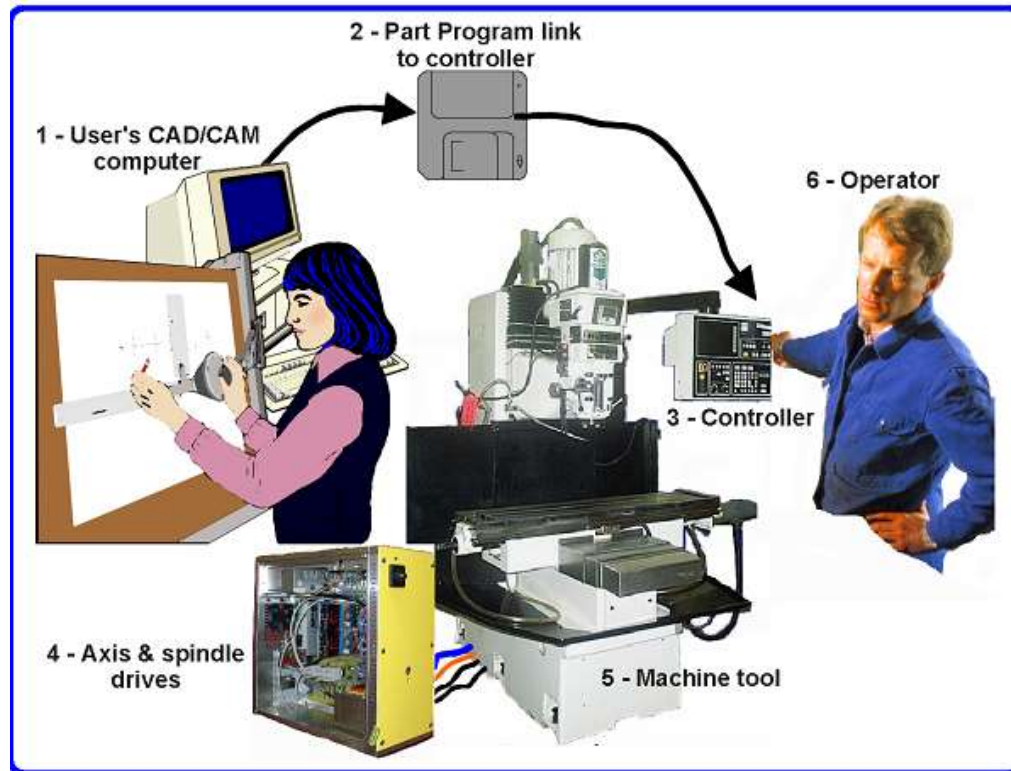

Figure 1: Main Parts of a CNC System

There are some of the important constituent parts and aspects of CNC machines to be considered in designing, for example Machine structure, Guide ways, Feed drives, Spindle bearings, measuring systems. Control of a machine tool by means of stored information through the computer is known as computer Numerical controlled. The information stored in the computer can be read by automatic means and converted into electrical signals, which operate the electrically controlled servo systems. Electrically controlled servo systems permits the slides of machine tool to be driven simultaneously and at the appropriate feeds and direction so that complex shapes can be cut, often with a single operation and without the need to reorient the work piece. Computer Numerically control can be applied to milling machines, lathe machines, grinding machines, boring machines, drilling machines.

The main controller subsystem is able to interpret and communicate the limits of any job, and it can directly control movement of the attachable tool heads. With direct connection to

the main controller subsystem, the pendant subsystem is able to accept jobs uploaded through a flash drive, access information incoming through one of the three communication ports that are active, and can change specified rates of speed and the direction of movement of the machine.

The framework of the system is set up by the mechanical subsystem which will allow for movement in the x, y, z axes and specify spatial limitations of any acceptable job. The main controller, pendant, and mechanical subsystems are able to interact through power provided by the motor driver subsystem. The motor driver subsystem will contain a power supply that can accept input power through an electrical outlet plug-in, provide movement independently to the x, y, z axes, and can add an extra board to power the acceleration axis. [1][2]

2. Literature Review:

An entire manufacturing technology known as CAD/CAM has developed around the NC concept and, in addition, CNC with its powerful microprocessors and other enabling technologies proffered from the personal computing phenomenon has enabled the NC concept to branch into many variants, even a variant that is essentially record/playback. The latter of which are known in the industry as "teach lathes".

In addition, powerful and well-crafted human/machine interfaces allow the machine operator to prepare programs by means of interactive displays which request only the definition of the machining operation and its required parameters (such as a "pocket" and its dimensions) and not the actual tool paths with all the calculations that are there required. Anyone who knows machining concepts and blueprint interpretation can produce programs at the machine without the need for CAD/CAM. Nonetheless, the vast majority of programs are now produced with the aid of CAD/CAM and, for most users, CNC today (for all its gigahertz microprocessors and megabytes of real time kernel software) is conceptually little different from the first NC demonstrated by MIT in 1952.

If there is a notable difference in concept, it is that CNC is no longer just for the spindle/cutting tool process of stock removal. It is for any processes that can be carried on machine tool motion platforms and that benefit from the separation of programming from operations, that is, from the CAD/CAM technology. These include lasing, welding, friction stir welding, ultrasonic welding, flame cutting, bending, spinning, pinning, gluing, fabric cutting, sewing, tape and fiber placement, routing, picking and placing (PnP), sawing and undoubtedly, the industrial processes of tomorrow. [3]

Basic CNC Principles:

All computer controlled machines are able to accurately and repeatedly control motion in various directions. Each of these directions of motion is called an axis. Depending on the machine type there are commonly two to five axes. Additionally, a CNC axis may be either a linear axis in which movement is in a straight line, or a rotary axis with motion following a circular path.
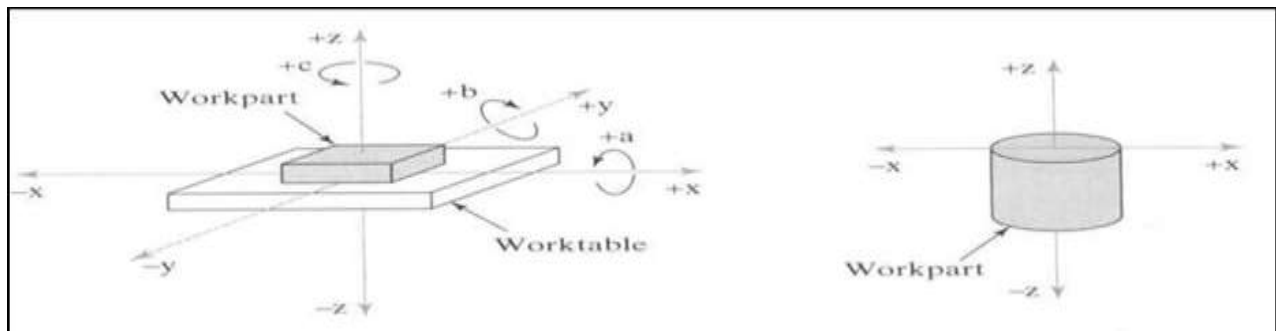

Figure 2: Coordinate system used in NC: (a)for flat and prismatic work (b)rotational work

Modern CNC Machine:

Modern CNC machines offer increased productivity due to stiffer machine and spindle designs, more powerful motors, high pressure coolant (up to 1000 psi) that floods the cutting zone, automatic tool changers, digital work piece and tool probing, and/or horizontally mounted spindles. [4]

Figure 3: Modern CNC Machine

3. Methodology & Construction:

The design and construction of Computer Numerically Controlled (CNC) machines differs greatly from that of conventional machine tools. The CNC machines often employ the various mechatronics elements that have been developed over the years. There are some of the important constituents parts and aspects of CNC machines to be considered in their designing
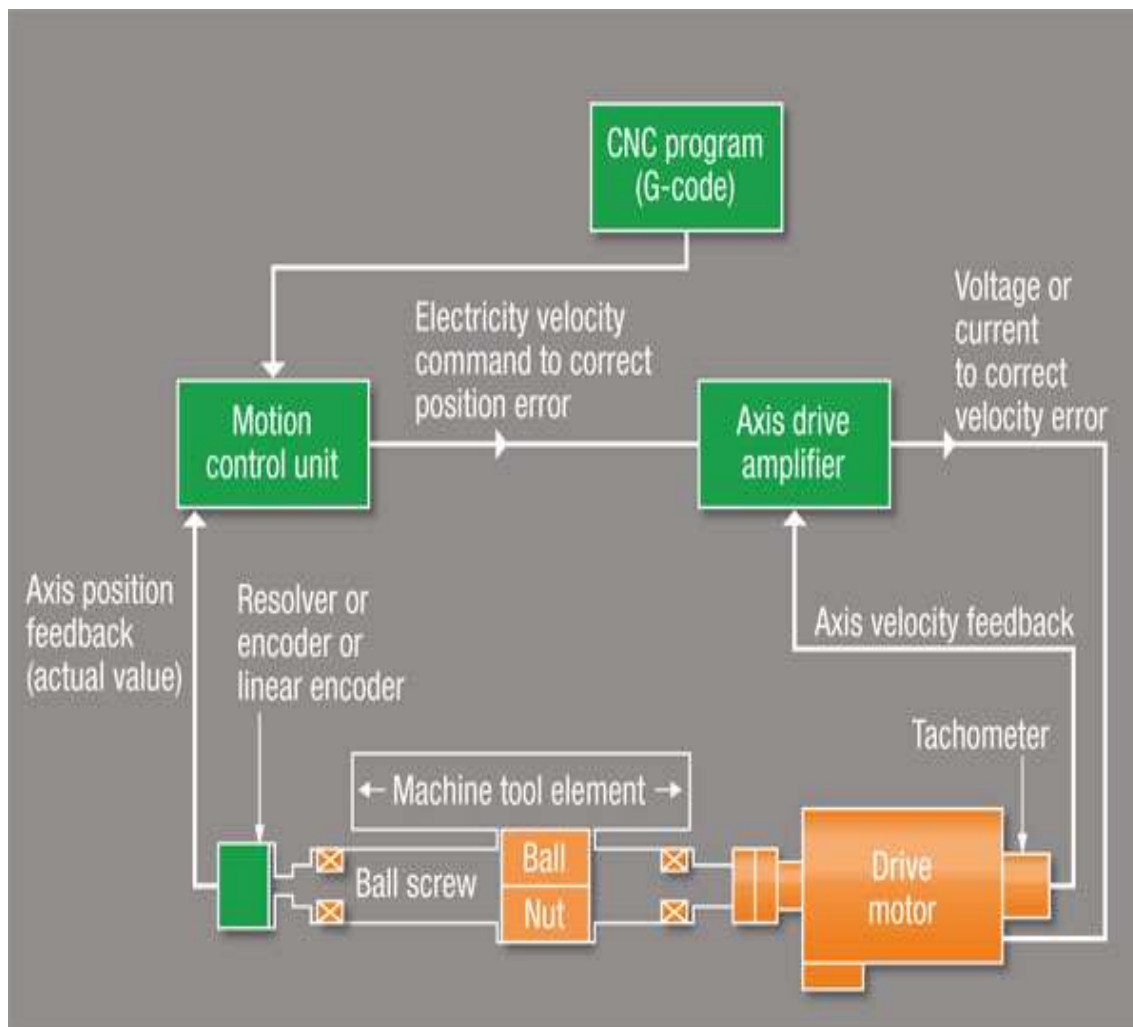

Figure 4 : Block Diagram of a CNC Machine

CNC Machine Design:

The framework of the system is set up by the mechanical subsystem which will allow for movement in the x, y, z axes and specify spatial limitations of any acceptable job.
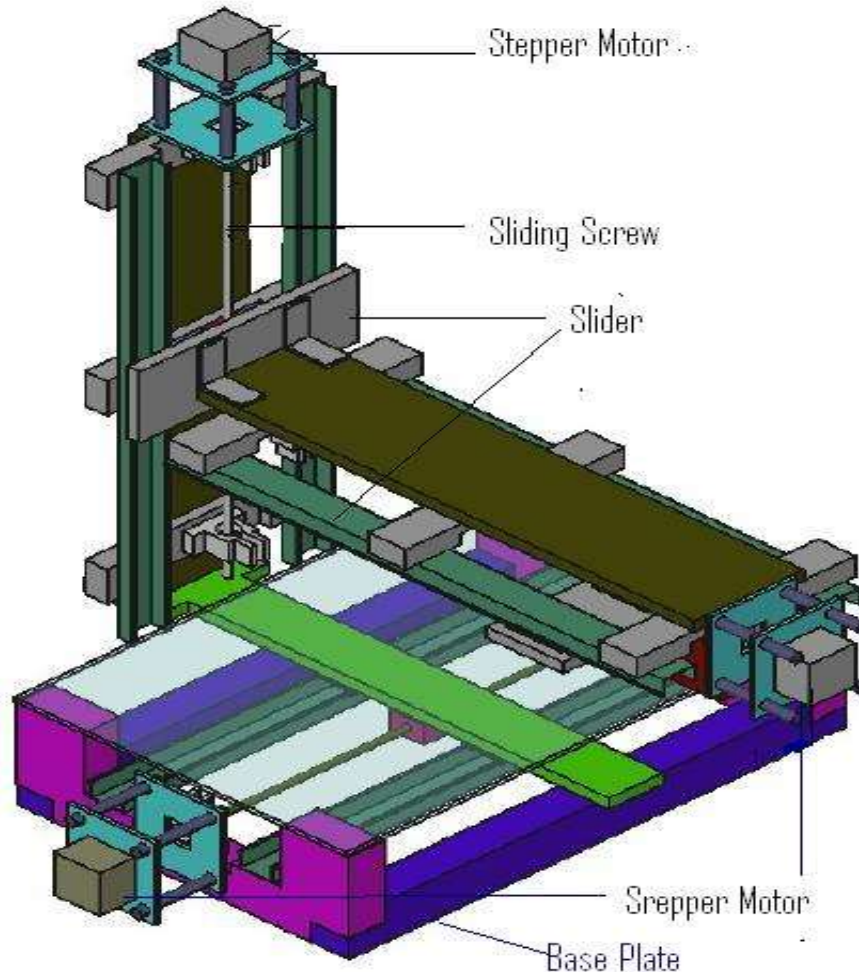

Figure 5: Isometric view of the CNC Machine (project).

The main controller, pendant, and mechanical subsystems are able to interact through power provided by the motor driver subsystem. The motor driver subsystem will contain a power supply that can accept input power through an electrical outlet plug-in, provide movement independently to the x, y,

z axes, and can add an extra board to power the acceleration axis

The overall 3D CAD diagrams of the machine are given. The CNC machine is a system that is able to accept numerical control inputs to machine a part specified by the exact positioning of the inputs
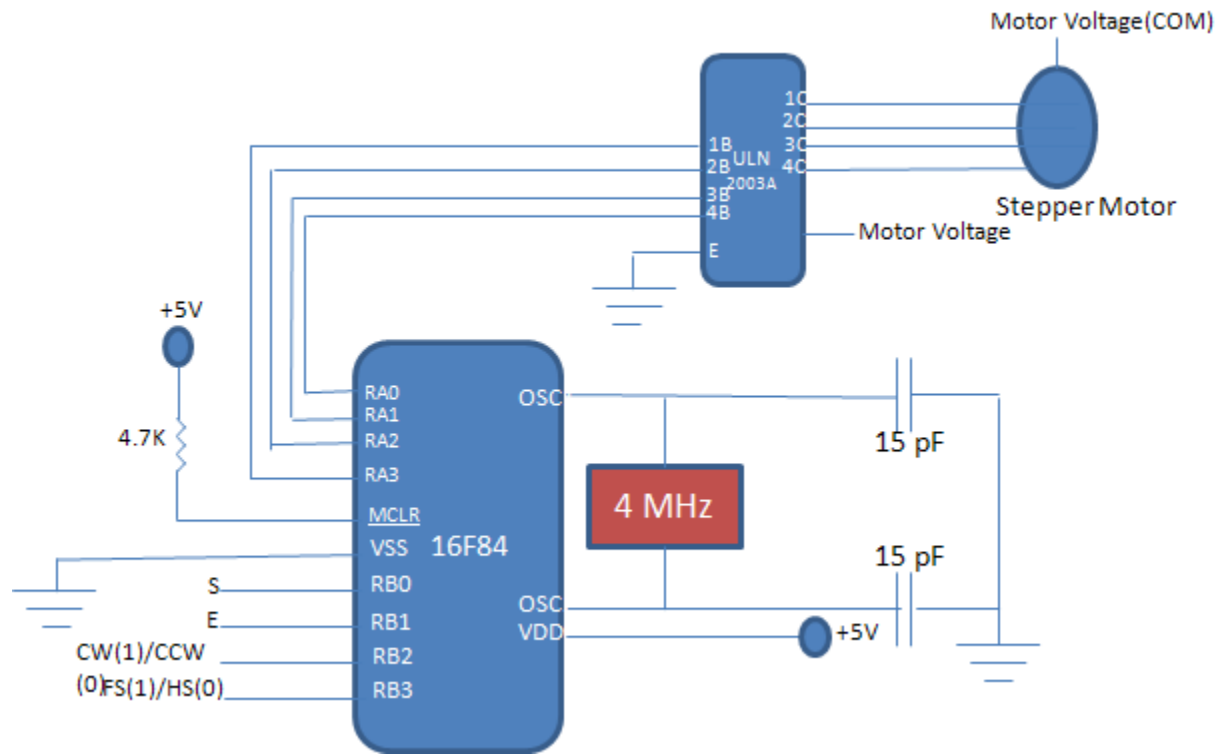*CNC control circuit diagram:*

Figure 6: Schematic Diagram of the one axis CNC Controller.

This is a one axis stepper motor controller. In this circuit one 16F84A MCU is used with 4 MHz Oscillator. ULN2003A is used for switching for the sequence of pulses for the stepper motor. The stepper motor is connected with the output of the ULN2003A. The common terminal of the ULN and the stepper is connected with motor supply voltage. Other connections are done as shown in figure. From the S pin the steps are supplied from the controller software. E pin is for enabling the controller. CW/CCW pin is for setting the clockwise and anticlockwise rotation. FS/HS is for full step and half step pulse sequence. [6]

CNC machine controlling circuit:

Figure 7: CNC controller circuit.
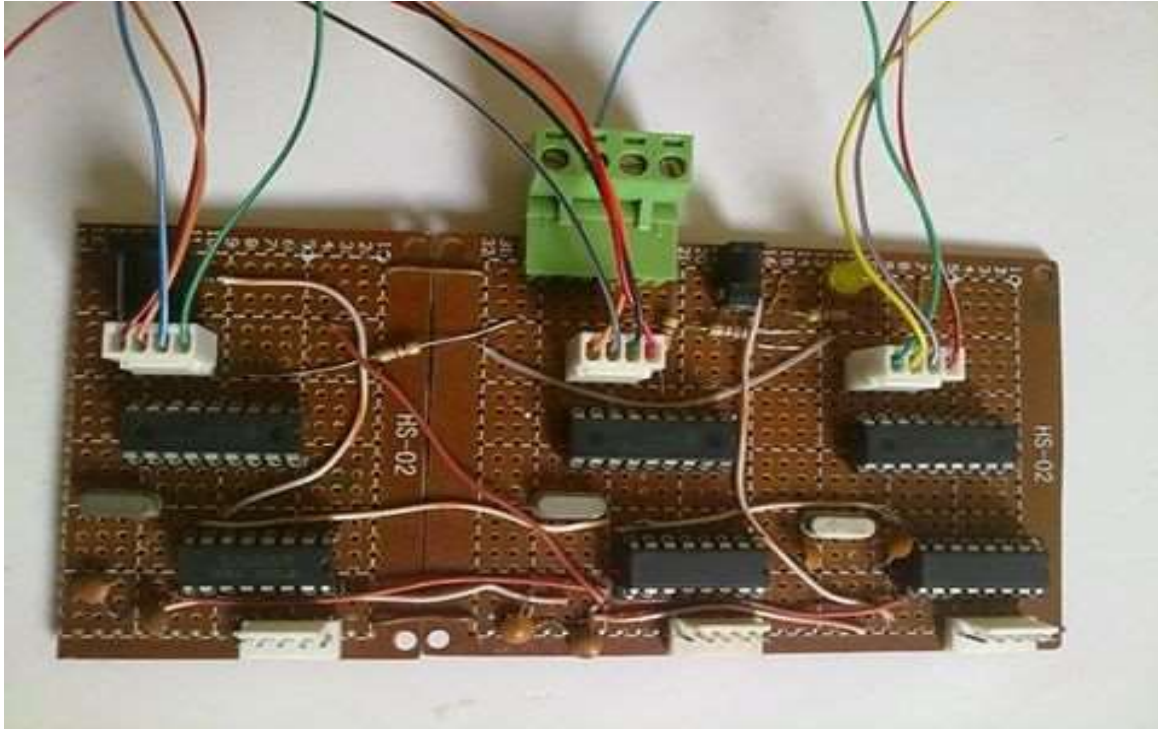
As per our circuit design we made this controller circuit. We used our Mechatronics Lab to fabricate this circuit.

Components of project:

SI No.	Name of Components	Quantity
1	Microcontroller PIC16F84	03 Pcs.
2	IC(ULN 2003a)	03 Pcs.
3	Bipolar Stepper Motor	03 Pcs.
4	15pF Ceramic Capacitor	10 Pcs.

5	Wire Connector Rails (12 slots)	03 Pcs.
6	Oscillator 4MHz	05 Pcs
7	Connecting wire	01 Meter
8	PCB Board	03 Pcs.
9	Resistors,4.7k	10 Pcs
10	Thread Rod	3M
11	Square bar	3 pcs
12	Plastic Base Board for Structure	(12X18'') 7pcs
13	Bearing	3pcs
14	Transparent Plastic Board	1 pcs
15	Bearing Block	6 pcs
17	Nut & Bolt	(15x6mm) 50pcs

Description of works:

After selecting the project design we tried to fabricate it with MS plate and faced some difficulties such as over weight of Machine structure. We assumed that from thumb rule our selected stepper Motor could not carry the load. The works took long time because we had to erect the job from deferent workshops. Then our thesis supervisor sir advised us to make the CNC machine by combined use of MS Plate bar, SS screw bar and Plastic sheet. Actually it is complex electro-mechanical base work. We had to face lots of problems because of insufficient mechanical workshop facilities. The electrical circuit we designed was tried to be made many times as it was not perfect.
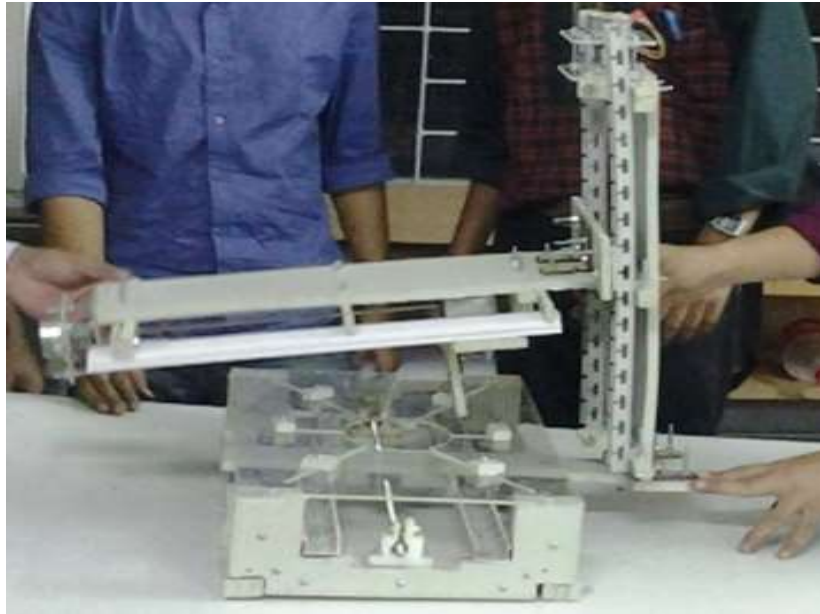
Figure 8: Assembling the CNC Machine.

After arranging all the required materials we started to fabricate all the parts of the CNC machine. We used Steel ruler, Steel measuring tap, digital Vernier Caliper to take the precious measurement of the CNC machine Parts. For cutting of the SS screw bar we used a special types Hacksaw Blade and used half round file for smooth finishing.
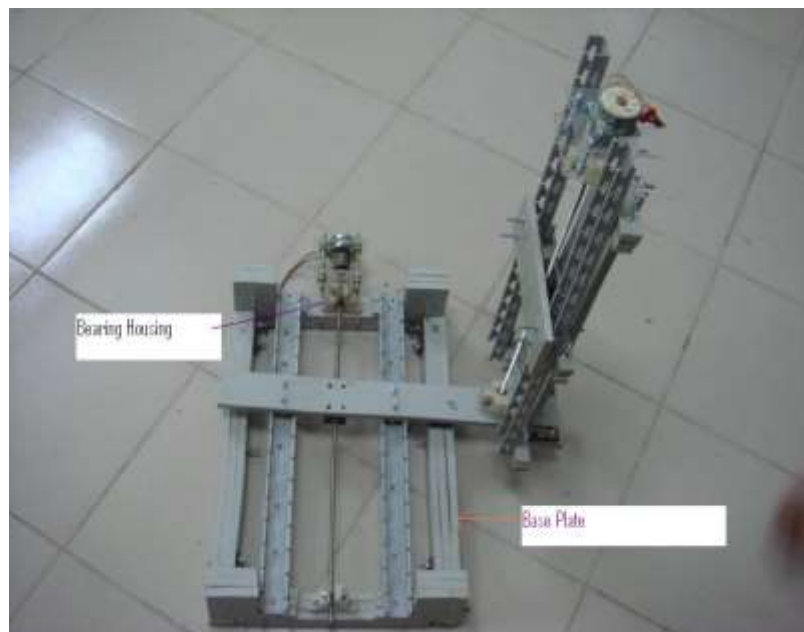
Figure 9: CNC machine (under construction).

We designed and made the bearing Block several times because when bearing is to set into the block it should be completely fit with outer. For assembling the stepper motor with the lead screw throw the bearing we used two pieces square shaped transparent plate. All of assembling works we did at our mechatronics lab. For joining the parts we used different sizes of screws.

After completing the X axis portion the CNC machine we checked with our control either it works or not. As per working principle of the CNC machines when stepper motor rotates then tool post move on the slider. But the slide could not move easily due to unparalleled alignment. Then we corrected it. With the same working procedure we completed Y-axis potion of the CNC machine. Then we checked and tested X-Y axis potion at a time and found it as it was working in order. We assembled the Z-axis portion also. But when we joined it with base machine then we found some problems. The machine got tilted. The parts of the slider and supports would have required rigid bars.

Figure 10: Completed CNC Machine.

After completion weight of the different parts of different positions became unbalanced. Because balancing is an important part of machine design and materials selection. Our manufactured CNC machine is not in proper balanced position with its entire parts. We

found some positions are little bit inclined from right position. So we should have used heavier part for Base and horizontal (X) portions, lighter part for vertical (Y) portion and competitively lighter parts for top (Z)

portion where tool is to be mounted. Some of points we could use extra support of thin MS flat (3mm) bar to prevent the inclination of the plastic frames.

Firmware of the One Axis CNC Controller [6][7][8]

```
'Firmware for CNC Machine Controller in PIC Basic of PIC Simulator IDE
'Developed by Arfuzzaman,
'(c) Arfuzzaman 2014
'By default, this program will use RA0 , RA1 , RA2, RA3 as Stepper motor
output for 0,1,2,3 bits of unipolar stepper motor
'RB0 = Step input used as interrupt pin
'RB1 = Enable
'RB2 = Clockwise(High)/Anticlockwise(low) Direction
'RB3 = Full(high)/Half(low) step

TRISB = 0xff  'set all PORTA pins as inputs
TRISA = 0x00  'set all PORTA pins as outputs
INTCON.INTE = 1  'enable RB0/INT interrupts
INTCON.GIE = 1  'enable all un-masked interrupts


Dim seq1(8) As Byte
Dim seq2(8) As Byte
Dim index As Byte
Dim checkstate As Byte

seq1(0) = %00001010
seq1(1) = %00001001
seq1(2) = %00000101
seq1(3) = %00000110


seq2(0) = %00001010
seq2(1) = %00001000
seq2(2) = %00001001
seq2(3) = %00000001
seq2(4) = %00000101
seq2(5) = %00000100
seq2(6) = %00000110
seq2(7) = %00000010


index = 0
checkstate = 0  'Half Step
RA = seq1(0)
RA = seq1(1)
RA = seq1(2)
RA = seq1(3)
```

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```
start:

        If RB1 Then  'enable
                If RB3 Then  'Full step
                    If checkstate = 0 Then
                            checkstate = 1
                            If(index) Then
                                    index = index / 2
                            Endif
                    Endif
                    RA = seq1(index)
                Else  'Half step
                    If checkstate = 1 Then
                            checkstate = 0
                            If(index) Then
                                    index = 2 * index
                            Endif
                    Endif

                    RA = seq2(index)
                Endif
        Endif

Goto start
End

On Interrupt  'interrupt routine
        If RB1 Then  'enable
            If RB2 Then  'direction clockwise
                    index = index + 1
                    If RB3 Then  'full step
                            If index > 3 Then
                                    index = 0
                            Endif
                    Else  'Half Step
                            If index > 7 Then
                                    index = 0
                            Endif
                    Endif
            Else  'direction anticlockwise
                    If index > 0 Then
                            index = index - 1
                    Else
                            If RB3 Then  'Full step
                                    index = 3
                            Else  'Half Step
                                    index = 7
                            Endif
                    Endif
            Endif
        Endif
INTCON.INTF = 0  'enable new RB0/INT interrupts
Resume
```

4. Results & Discussion:

After building the project we were testing the CNC machine. Our project objective first is to design the CNC machine using microcontroller with accurate input and output pin. The working components such as stepper motors and other device are connected with the microcontroller. The program in the microcontroller is written by PICKit-2.

Our second objective is to construction a CNC machine which can work as a usual CNC machine. Our thesis project CNC machine is similar to the usual CNC machine and is small that can operate like usual CNC machine but the area of the machining is limited. CNC machine is all about using the computer as a means to control machines that carves useful objects from solid block to material.

During testing we found that the full machine became unbalanced because of flexible and soft slide ways. Because of that the device was tiled on one side. Due to that it was not tested for motion. Also the controller circuit is not made properly. Therefore the controller could not be checked at all. Theoretically the schematic and the firmware are perfect to operate with CNC software. Also selecting proper values for machining parameters such as cutting speed, feed rate, and depth of cut directly affects the machining economics in metal cutting process by the CNC software. Several cutting constraints must be considered in machining operations. In turning operations, a cutting process can possibly be complicated with a single pass or by multiple passes. Multi pass turning is preferable over single pass turning in the industry for economic reasons. That makes the problem of determining the optimal cutting conditions more difficult and complicated. Machining parameters can be determined based on machine operator's experience or by following the cutting handbook supplied by the equipment manufacturer. However, those data are not guaranteed to be optimal or even good for a particular cutting environment.

In the lab we tried to test the controller with the following logics and checked the outputs.

Full Steps						
Seq-0	**RA3**	**RA2**	**RA1**	**RA0**	**Forward**	**Reverse**
Seq-1	0	0	0	1	1	0
Seq-2	0	0	1	0	1	0
Seq-3	0	1	0	0	0	1
Seq-4	1	0	0	0	0	1
Half Steps						
Seq-1	0	0	0	1	1	0
Seq-2	0	0	1	0	1	0

Seq-3	0	1	0	0	1	0
Seq-4	1	0	0	0	1	0
Seq-5	0	0	0	1	0	1
Seq-6	1	0	1	0	0	1
Seq-7	1	0	1	1	0	1
Seq-8	1	1	0	0	0	1

Mach3 is a powerful application that can help CNC machine operators to send commands in order to complete their projects. It was developed as a program for hobbyists but it can also be implemented by companies and industrial users

The program intends to transform any computer into a CNC machine controller, able to send commands to a 6 axis cutter. It can import data from DXF, BMP, JPG or G-code files in order to control the device.

Figure 11: The Mach3 Software for CNC

5. Conclusion

We gathered huge of knowledge on mechatronics and its integration with software. We have already got an idea of computer numerical control and its application & implementation. We tried to make a CNC machine. The machine was constructed with locally available all

cheapest possible parts. The controller and motors were also obtained from local shops.

We much understood how this electro-mechanical, controlling systems and integration works. Now we realize one more step closer to the end of our program and once again proved to ourselves that this was the right choice for future career development. The project also made us feel

more confident on practice basis, where we felt as if we were working with this equipment for a long time. Though the machine could not be tested properly but it gave us basic idea about CNC machine's working principle, design and construction.

Working as a Team in this project contributed in our success, because we all were not familiar with every aspect of the requirements. One of us was good with programming, two with the Mechanical part and fabrications as with the machine and one with hardware as in the controlling circuit. Logical thinking is a very important aspect to build any circuit that has no idea of what environment it is going to deal with, and this aspect was in all four of us.

We always though in a problem logically first, worked on that logic. So we distributed our works within ourselves. By doing this project together we ended up getting knowledge and information on the areas we were weak in through sharing ideas and thoughts with each other. We had to modify lots of things such as circuit, program, Machine frames, motors, bearings and housings. During building this project we used different type hand tools. At last we were able to overcome by little bit modifications and readjustments. Finally we carried out project works quite successfully.

Future Recommendations:

• The CNC machine can be made with aluminum or steel frame.

• Different controlling approaches can be used.
• Machine can be designed more accurately to be balanced with frame loads by load analyses.
• The machine can be made with more precious and accurate stepper motors.

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