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MASTER  
In Electrical and Electronic Engineering  
Option: Computer

Title:  
Implementation of Low Cost Three Axis  
CNC Machine with Network Control

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Registration Number:........./2016
Dedication

To my beloved parents,

To my sister “Nassima”

To my brothers “Hicham, Ahmed, Massinissa”,

To all my Family,

To my best friends “Achour, Abdelmalek, El Mustapha, Slimane, Waffi”

To those who will be happy for me.

In the memory of my friend El Bachir

Adel MESSAOUDI
To my dear mother,

To my sister "Asmaa",

To my Brothers "Omar, Hocine, Mohamed",

And to all my beloved friends, my family members and those who I love,

In the memory of my dear father

BILLAL
Praise and glorification be only to Allah SWT, the Almighty, the most beneficent and the most merciful, whose blessing and guidance have helped us to finish this work.

We would like to express our sincere gratitude to our supervisor Dr. Benzekri who accepted to supervise us for this work, and for his inspirations, encouragement and guidance throughout our project.

Our warm thanks to all IGEE family (students, teachers, workers) who all contributed in some way to this project.
Abstract

Increase in the rapid growth of Technology significantly increased the usage and utilization of Computer Numerical Control (CNC) systems in industries but at considerable expensive. The idea on fabrication of low cost CNC came forward to reduce the cost and complexity in CNC systems. This work discusses the design and implementation of low cost three dimensional CNC machine using off-the-shelf components. We built the mechanical system which contains three axis X, Y and Z where three stepper motors and their drivers were used to move it. A microcontroller was used to control the stepper motors after interpreting the streamed g-code received from USB/Serial port of the Raspberry Pi where it offers two ways of controlling the machine. The first one is local control (machine location) where a GUI application was developed using Python programming language. The second is a control via network where Raspberry Pi hosts the web application that was developed using Node.js and bootstrap framework.

The prototype CNC works well and some designs and models were successfully and accurately produced.
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<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>AC</td>
<td>Alternating current</td>
</tr>
<tr>
<td>BLU</td>
<td>Basic Length Unit</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>CAM</td>
<td>Computer Aided Manufacturing</td>
</tr>
<tr>
<td>CLK</td>
<td>Clock</td>
</tr>
<tr>
<td>CNC</td>
<td>Computer Numerical Computer</td>
</tr>
<tr>
<td>CSS</td>
<td>Cascading Style Sheets</td>
</tr>
<tr>
<td>CW</td>
<td>Clockwise</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>EDM</td>
<td>Electrical Discharge Machine</td>
</tr>
<tr>
<td>EEPROM</td>
<td>Electrically Erasable Programmable Read-only Memory</td>
</tr>
<tr>
<td>G-code</td>
<td>Geometric Code</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>HDMI</td>
<td>High Definition Multimedia interface</td>
</tr>
<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
</tr>
<tr>
<td>HTML</td>
<td>Hypertext Markup Language</td>
</tr>
<tr>
<td>HTTP</td>
<td>HyperText Transfer Protocol</td>
</tr>
<tr>
<td>IDE</td>
<td>Integrated Development Environment</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of things</td>
</tr>
<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>OS</td>
<td>Operating System</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
</tr>
<tr>
<td>PWM</td>
<td>Pulse Width Modulation</td>
</tr>
<tr>
<td>SRAM</td>
<td>Static Random Access Memory</td>
</tr>
<tr>
<td>SSH</td>
<td>Secure Shell</td>
</tr>
<tr>
<td>UART</td>
<td>Universal Asynchronous Receiver Transmitter</td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
</tr>
<tr>
<td>WAN</td>
<td>Wide Area Network</td>
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</table>
INTRODUCTION
Requirements of today’s industry are to produce large quantity and quality products with low production and installation cost. These tasks can be easily completed by the machines which are controlled by computers to make work easier with ultra-precision and less human caused errors. These are commonly known as CNC (Computer Numeric Control) Machines.

Different kinds of CNC machines cover an extremely large variety. Their numbers are rapidly increasing, as the technology development advances. It is hard to identify all the applications but their machining principle is the same.

The work presented in this project is an implementation of a 3-axis CNC prototype. Starting by introducing some generalities on CNC machines, also showing their applications and advantages. Next, the components used to construct a simple CNC machine either from the mechanical side or the software and electrical side were introduced. In the third chapter, the design and realization of a microcontroller based embedded three dimensional CNC machine was presented. Detailed descriptions of different modules along with technical details of their implementations have been given.
CHAPTER ONE

INTRODUCTION TO CNC MACHINES
1. Introduction

The Computer Numerical Control (CNC) machining is a process used in the manufacturing sector that involves the use of computers to control machine tools. Under CNC machining, machine tools function through numerical control. A computer program is customized for an object and the machines are programmed with language called G-code that essentially controls all features like feed rate, coordination, axis motions, location and speed [1]. Figure 1-1 shows the whole CNC system built in this project with its all components.

![Figure 1-1 The whole CNC system](image)

2. History of CNC machines

CNC is the combination of Numerical Control (NC, the controlling of machinery using numbers either to manipulate discrete controls, or more directly via punch cards or tapes or other electrical signals) and computers. The history starts with early efforts to automate industrial machinery such as looms. The table 1-1 shows the timeline of CNC development.

<table>
<thead>
<tr>
<th>Years</th>
<th>Development</th>
<th>Years</th>
<th>Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1801</td>
<td>The Jacquard loom is a mechanical loom, invented by Joseph Marie Jacquard, first demonstrated in 1801, that simplifies the process of manufacturing textiles with complex patterns using punch cards.</td>
<td>1985</td>
<td>Computer Aided Design (CAD) The Automatically Programmed Tool project and the report, then later project, Computer-Aided Design: A Statement of Objectives 1960 of Douglas T. Ross were the first Computer Aided Design systems.</td>
</tr>
<tr>
<td>Year</td>
<td>Event</td>
<td>Year</td>
<td>Event</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------------------------------------------</td>
<td>------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>1810</td>
<td>Milling machines which make use of rotary filing are developed for metalworking.</td>
<td>1959</td>
<td>First Computer Numerical Control system. By Aircraft Industries Association (AIA) and Air Material Command</td>
</tr>
<tr>
<td>1822</td>
<td>Charles Babbage conceives of the Difference Engine, an early mechanical computer for calculating polynomials.</td>
<td>1984</td>
<td>Stereolithography (3D printing) and STL File Format invented by Chuck Hull of 3D Systems Corp.</td>
</tr>
</tbody>
</table>
| 1915 | The first electrical power tool, the wood router inaugurated the idea of bringing the tool to the piece being worked, a concept central to CNC. | 1989 | - Enhanced Machine Controller  
- Selective Laser Sintering |
| 1931 | Servos and Selsyns, adding power to Cams didn't address the matter of controlling the position accurately under all possible circumstances. Servomechanisms and selsyns allowed the machine to provide measurement information as it worked, increasing accuracy. | 1990 | fused deposition modeling (FDM)  
Plastic extrusion technology most widely associated with the term "3D printing" was commercialized by Stratasys under the name fused deposition modeling. |
| 1940 | Tracer Control, adding hydraulics to Cams allowed for the use of a stylus to trace a template controlling a machine which would cut a part to match. | 1995 | 3D printing trademarked, Z Corporation commercialized an MIT-developed additive process under the trademark 3D printing (3DP) |
| 1946 | Numerical Control, John T. Parsons developed Numerical Control (NC) so as to be able to fabricate parts for helicopter rotors for the Sikorsky Helicopter Company using funding from the United States Air Force. | 2000 | Enhanced Machine Controller released to the public domain. This eliminates the expense of proprietary machine control software, making the machines more affordable. |
| 1949 | Numerical Control using Punch Cards, Parsons turned to M.I.T. to make use of servomechanisms or to otherwise improve the accuracy of NC. under an Air Force contract for the construction of two "Card-a-matic Milling Machines", a prototype and a production system. | 2005 | Reprap, Development of the reprap, a 3D printer that can print most of its own components. |
1951 M.I.T. attempted to develop a machine on their own, using roller chains to manipulate the machine along three axes (X, Y, and Z) and used standard 7-track punch tape for input.

2011 Shapeoko
A low-cost, open source CNC mill designed by Edward Ford.

1953 The Air Force Numeric Control and Milling Machine projects formally concluded in 1953, but development continued at the Giddings and Lewis Machine Tool Co. and other locations.

2013 Shapeoko 2
The second version of which was announced on 21 October.

1955 G-Code/Magnetic Tape
Electronic control was added with the use of magnetic tapes to record and play back calculated machine paths, which are described using the nascent G-code.

2014 ShapeOko3
Third (current) version announced 9 December.

Table 1-1: The history of CNC machine developing [3]

3. Types of CNC machine tools

Different kinds of CNC machines cover an extremely large variety. Their numbers are rapidly increasing, as the technology development advances. It is hard to identify all the applications; they would make a long list. Popular types of CNC will be presented including the CNC router, which is our project.

3.1 CNC routers

Figure 1-2 shows a CNC router, a very common piece of machinery. These machines are built exclusively to be operated by CNC technology and have no human interface other than through the computer.

Routers are generally for producing larger work and more commonly built with the idea of cutting wood, plastics, composites, aluminum, steel, plastics, and foams. Also, Routers are most commonly found in a 3 axis setup (X, Y and Z). This set up will allow cutting of basic profiles and 3-dimensional relief machining. There are also CNC router which are 4, 5 or even 6 axis, these machines are more suited towards cutting more complex shapes or prototype models.

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Figure 1-2: CNC router, 3-axis, 1-spindle, steel PEM-1325-x series Perfect Laser Co., Ltd. China [4]

3.2 CNC mills and machining centers

Figure 1-3 illustrates a CNC mills - sometimes called CNC milling machine. It is usually small, simple machine, without a tool changer or other automatic features. Their power rating is often quite low. CNC machining center are far more popular and efficient than drills and mills, mainly for their flexibility. The flexibility is enhanced by automatic tool changing, rotary movement of additional axes, and a number of other features. There are two basic designs of CNC machining center. They are the vertical and the horizontal machining center. The programming process is the same for both designs, but an additional axis is added to the horizontal design (indexing axis for the table, or fully rotary axis for simultaneous contouring).

Figure 1-3: CENTROID milling machine [5]
3.3 CNC Lathes and Turning Centers

A CNC lathe is usually a machine tool with two axes, the vertical X axis and the horizontal Z axis, Figure 1-4. The modern lathe design can be horizontal or vertical. Several different designs exist for either group.

![CNC Lathe Image](image.png)

Figure 1-4: 15L Slant-PRO CNC Lathe [6]

3.4 CNC Plasma Cutter

CNC plasma cutters are very similar to CNC routers in size and setup, however plasma cutters don’t require as much of a powerful set up because as opposed to dragging around a spinning tool in material they fly above the table with a plasma torch.

3.5 3D Printer

A 3D printer or 3-dimensional printer uses a similar set up as a CNC router or laser cutter, except it uses a plastic extruder. This plastic extruder pushes out hot plastic through a tiny hole and slowly, layer by layer deposits enough plastic to build up a completed part.

4. Open- and Closed-Loop CNC Machining

Open-loop and closed-loop machining represents the differences between a machine with and without feedback and control mechanisms. An open-loop machine is one which can send signals from the controller to the machine tool, but receives no information in return which is our case. This typically represents a basic system which requires human control and
moderation[7]. Closed-loop machining processes are those which possess the ability to send signals back from the machine tool to the controller. These signals may contain important information about the current cutting conditions and are very useful in making automatic adjustments during operation. These adjustments help minimize detrimental conditions such as tool deflection or work piece slip. The cost of closed-loop machinery is considerably more expensive than the open-loop counterparts, but offers robust process control.

5. Applications of CNC machines

CNC Machining has revolutionized the manufacturing industry. Whether it is a small manufacturing unit or a large global company, CNC machines find applications in almost all types of industries. That’s because when it comes to producing complex parts in metal or any other material, these computer controlled machine tools are ideal because of their high levels of accuracy, precision and speed. So let’s take a look at the various industries where CNC is used.

Metal Removal Applications – CNC machines are extensively used in industries where metal removal is required. The machines remove excess metal from raw materials to create complex parts. A good example of this would be the automotive industries where gears, shafts and other complex parts are carved from the raw material. CNC machines are also used in the manufacturing industries for producing rectangular, square, rounded and even threaded jobs. Metal Fabrication Industry – Many industries require thin plates for different purposes. These industries use CNC machines for a number of machining operations such as plasma or flame cutting, laser cutting, shearing, forming and welding to create these plates.

Electrical Discharge Machines (EDMs) remove metal from the raw material by producing sparks that burn away the excess metal. EDM machining through CNC automation is carried out in two different ways; first through Wire EDM and second through Vertical EDM [8].

Besides these industries, CNC machines also find use in the wood working industries for various operations like drilling and routing.
6. Literature Review

In the past, many developments and research have been made to enhance the efficiency of manufacturing operations as well as decreasing the cost of CNC machines. There are a significant number of useful papers in the area of CNC machining.

- In [9] the authors discussed how to develop a low cost CNC router which is capable of 3-axis simultaneous interpolated operation.
- In [10] a mini 2-axis CNC machine design was explained by showing the criteria needed to develop the machine and the software used to control it.
- In [11] the Authors study The ability of a CNC machine to create parts for itself, and an evaluation of whether or not the machine is able to improve itself by creating new machine parts.

7. Advantages and Disadvantages of CNC Machining

CNC machines as all others technologies has advantages and disadvantages.

7.1 Advantages

1. CNC machines can be used continuously 24 hours a day, 365 days a year and only need to be switched off for occasional maintenance.
2. CNC machines are programmed with a design which can then be manufactured hundreds or even thousands of times. Each manufactured product will be exactly the same.
3. Less skilled/trained people can operate CNCs unlike manual lathes / milling machines which need skilled engineers.
4. CNC machines can be updated by improving the software used to drive the machines.
5. Modern design software allows the designer to simulate the manufacture of his/her idea. There is no need to make a prototype or a model. This saves time and money.
6. One person can supervise many CNC machines as once they are programmed they can usually be left to work by themselves [12].

7.2 disadvantages

1. CNC machines are more expensive than manually operated machines, although costs are slowly coming down.
2- Less workers are required to operate CNC machines compared to manually operated machines. Investment in CNC machines can lead to unemployment.

3- Many countries no longer teach pupils / students how to use manually operated lathes / milling machines etc... Pupils / students no longer develop the detailed skills required by engineers of the past. These include mathematical and engineering skills.

8. Conclusion

In this chapter, some generalities on CNC machines have been presented. Starting by their general definition, and then showing their developing timeline.

In addition, different types of CNC machines have been discussed by giving their definitions and uses. Applications and advantages of using CNC have been described and reported.
CHAPTER TWO

HARDWARE AND SOFTWARE DESCRIPTION OF CNC MACHINE
1. **Introduction**

Most industrial CNC equipment is complex and requires a serious investment. There are also simpler and less expensive variants that can be applied to simple machining operations. This chapter takes a closer look at the components used to construct a simple CNC router machine that can be a helpful first step along the path to understand a CNC equipment. The parts composing a simple CNC machine can be acquired through conventional means or crafted using commercially available products. There are three important components of the computer numerical control as shown in the Figure 2-1.

- **Component 1** - Mechanical (Machine tool).
- **Component 2** - Electrical and electronic.
- **Component 3** - Program of instructions.

![Figure 2-1 CNC components](image)

2. **Mechanical side (Machine tool)**

The mechanical subsystem of a CNC provides the means needed to cut and machine various materials for a given job. The choice of materials has a direct impact on performance, precision, repeatability, longevity, and mechanical noise transfer into the parts. The mechanical subsystem is comprised of the guide system, the drive system, and the frame housing structure, Figure 2-2. Each of these systems has a direct impact on the aforementioned qualities of a CNC.
2.1 CNC router mechanical parts

2.1.1 Guide Rail Design

The first frame subsystem design to consider would be a conventional railing system, which consists of a linear motion bearing and shaft assembly, which would simply allow unrestricted movement along their lengths. The most logical rail design to consider, given the design specifications and size requirements, would be the sort of railing that could be supported in some way to handle the loads applied to it without much deflection. For instance, the railing system shown in Figure 2-3 has a simple steel shaft railing system and is lightweight; the other one is the simplest and most applicable railing system which involves a wood guide rail. This system is capable of higher loading capacities with stability in handling off-balanced loads.
Chapter Two                      Hardware and Software Description of CNC machine 

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Figure 2-3 railing system used in this project

2.1.2 Drive designs

The purpose of the drive mechanics is to transfer the torque provided by the electric drive motors into linear motion to move the tool head. Since CNC machines require linear movement in multiple axes, timer belt and pulleys systems, Figure 2-4, are most often used to accomplish this goal. These systems offer a simple and compact means of transmitting power and motion with excellent reliability. For these machines, the pulleys are turned by motors, generating linear motion. Timer belts and pulleys are used because they are low cost, less noise, no lubrication, less maintenance, higher efficiency.

Figure 2-4 Timing belt used for linear positioning

2.1.3 Frame

CNC frame materials need to have some strength in order to support the weight of the gantry and the cutting head as well as with stand forces resulting from the routing process. Stiffness is also required to prevent any deflection due to both static forces and dynamic
forces resulting from the acceleration of the tool head. Weight is also important because the mass of the frame contributes to both the static and acceleration forces.

The best frame material would accomplish and offer excellent machinability and be available at a low cost.

2.2 Description of CNC mechanism

CNC router machine operate on three axes: X, Y and Z. The x-axis runs left to right (horizontal), the y-axis runs from the front of the machine or piece of material to the back (vertical) while the z-axis runs up and down perpendicular to the x-axis.

While the function of each machine determines the specifics of how it is operated, some basic operations hold for all CNC machines.

2.3 Principles of CNC

2.3.1 Basic Length Unit (BLU)

Each BLU unit corresponds to the position resolution of the axis of motion. For example, 1BLU = 0.0001mm means that the axis will move 0.0001mm for every one electrical pulse received by the motor. It is also referred to as Bit (binary digit) [13].

Pulse = BLU = Bit

2.3.2 Point-to-Point systems

Point-to-point systems are those that move the tool or the workpiece from one point to another and then the tool performs the required task. Upon completion, the tool (or workpiece) moves to the next position and the cycle is repeated, Figure 2-5. The simplest example for this type of system is a frilling machine where the workpiece moves. In this system, the federate and the path of the cutting tool (or workpiece) have no significance on the machining process. The necessary of positioning depends on the system’s resolution in terms of BLU.
2.3.3 Continuous path system (Straight cut and contouring systems)

These systems provide continuous paths such that the tool can perform while the axes are moving, enabling the system to generate angular surfaces, two-dimensional curves, or three-dimensional contours. An example is a milling machine where such tasks are accomplished. Each axis might move continuously at a different velocity. Velocity error is significant in affecting the positions of the cutter. It is much more important in circular contour cutting where one axis follows sine function while the other follows cosine function. Figures 2-6 illustrates point-to-point and continuous path for various machines.

Figure 2-5 Cutter path between holes in a point-to-point system[13]

Figure 2-6 Schematic illustration of drilling, boring, and milling with various paths[13]
2.3.4 Incremental and absolute systems

CNC systems are further divided into incremental and absolute systems. Figure 2-7. In incremental mode, the distance is measured from one point to the next. An absolute system is one in which all the moving commands are referred from a reference point (zero point or origin). Both systems are incorporated in most CNC systems. For an inexperienced operator, it is wise to use incremental mode.

(a) Absolute versus incremental; In absolute positioning, the move is specified by x = 6, y = 8; in incremental, the move is specified by x=4, y=5 for the tool to be moved from (2,3) to (6,8)

(b) Drilling 5-holes at different locations

Figure 2-7 Incremental mode versus absolute mode[13]

3. Electrical and electronic side

CNC electronics are a vital part of any CNC machine. Aside from the motors and CNC controllers, there are many electronic components that assist in the machine operation. This section will cover all the electronics and electrical components involved with a CNC router and help to understand how they come together with other components to create a working machine.
3.1 Stepper motor

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shaft's rotation is directly related to the frequency of the input pulses and the angular rotation is directly related to the number of input pulses applied [14].

As most motors, the stepper motors consists of a stator and a rotor. The rotor carries a set of permanent magnets, and the stator has the coils. The internal structure of a generic stepper motor is shown in Figure 2-8.

![Figure 2-8 Internal structure of a generic stepper motor](image)

The motors used in our project have a step angle of 1.8 degrees, Figure 2-9. The rotation of these motors is controlled by the electric current which pours into $X$ coil, $\overline{X}$ coil, $Y$ coil and $\overline{Y}$ coil using full-step mode as shown in Table 2-1.

<table>
<thead>
<tr>
<th>Step $N^\circ$</th>
<th>$X$</th>
<th>$\overline{X}$</th>
<th>$Y$</th>
<th>$\overline{Y}$</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0.0°</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1.8°</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>3.6°</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>5.4°</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>7.2°</td>
</tr>
</tbody>
</table>

Table 2.1 Full step sequence of stepper motor

In this project, the stepper motors shown in Figure 2-9 are characterized by:

- Drive system: Unipolar.
- Step angle: 1.8° full step / 0.9° half step.
• Voltage and current: 9V at 400 mA.
• Resistance per phase: 17 ohms.
• Ambient temperature: -10°C to +55°C.

3.2 Stepper motor driver

A motor driver is a little current amplifier; the function of motor drivers is to take a low-current control signal and then turn it into a higher-current signal that can drive a motor. There are many different kinds of motor drivers, the one used in this project is the TB6560.

3.2.1 TB6560 overview

Figure 2-10 illustrates the stepper motor driver TB6560 which is an excellent micro-stepping driver that uses TOSHIBA TB6560 Chip, based on pure-sine current control technology. Owing to the above technology and the self-adjustment technology (self-adjust current control parameters) according to different motors, the driven motors can run with smaller noise, lower heating, smoother movement and have better performances at higher speed than most of the drives in the markets. It is suitable for driving 2-phase and 4-phase stepping motors.
3.2.2 TB6560 features

The TB6560 stepper motor driver has some features and characteristic:

- Low cost and good high-speed torque
- Supply voltage up to +32 VDC
- Output current up to 3.0A
- Pulse frequency up to 20 KHz
- Suitable for 2-phase and 4-phase motors
- Over-voltage and short-circuit protection
- 7 output current choices, max 3200 steps/rev
- Automatic idle-current reduction
- Slim size (96x61x37mm)

3.2.3 TB6560 circuit

The main component of this circuit is the Toshiba TB6560AHQ, which is a PWM chopper-type sinusoidal micro-step bipolar stepping motor driver IC. It is capable of low-vibration, high-performance drive of 2-phase stepping motors using only a clock signal [15]. Figure 2-11 shows the internal circuit of the TB6560 driver.

![Figure 2-11 Stepper motor driver TB6560 circuit [15]](image-url)
3.3 Arduino

The Arduino is an open hardware microcontroller platform. It consists of a printed circuit board with a microcontroller and all the supporting hardware necessary to use the microcontroller mounted on it. All of the designs for the PCB (printed circuit board) layouts are freely available. A simple IDE (integrated development environment) has been created, uses a simplified version of C++, making it easier to program and many code libraries have been written (Figure 2-12). This has simplified working with microcontrollers, and has opened up the world of microcontrollers to people who would otherwise have been deterred by the complexity of working with them.

The Arduino comes in many variations, and it is based either on an 8-bit Atmel AVR microcontroller or on a 32-bit Atmel ARM. An Arduino will be used to control the CNC router machine that will be built. The latest version is the Arduino UNO (Figure 2-13) based on the 8-bit Atmel ATMEGA328 microcontroller. UNO does not need a separate piece of hardware (called a programmer) in order to load a new code onto it simply use a USB cable.
3.3.1 Arduino UNO Specifications

Table 2-2 shows the characteristics of the Uno board used in our project.

<table>
<thead>
<tr>
<th>Microcontroller</th>
<th>ATmega328</th>
<th>DC Current per I/O pin</th>
<th>40 mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating voltage</td>
<td>5V</td>
<td>DC Current for 3.3V pin</td>
<td>50mA</td>
</tr>
<tr>
<td>Input voltage</td>
<td>7-12V</td>
<td>Flash memory</td>
<td>32 KByte</td>
</tr>
<tr>
<td>Input voltage(limit)</td>
<td>6-20V</td>
<td>SRAM</td>
<td>2 KByte</td>
</tr>
<tr>
<td>Digital I/O pins</td>
<td>14</td>
<td>EEPROM</td>
<td>1 KByte</td>
</tr>
<tr>
<td>PWM Digital I/O pins</td>
<td>6</td>
<td>Clock Speed</td>
<td>16 MHz</td>
</tr>
<tr>
<td>Analog input Pins</td>
<td>6</td>
<td>Bootloader size</td>
<td>0.5 KByte</td>
</tr>
</tbody>
</table>

Table 2-2 Arduino UNO specifications [16].

3.3.2 Arduino Programming Language

Using C to program the Arduino means usually being able to create smaller programs, and with more fine grained control of what happens. C is adopted worldwide to program for small microprocessors because it gives a good trade-off between development effort and program efficiency, and because of its history there are well-optimized libraries, extensive guides and ways to solve problems. Arduino IDE uses the avr-gcc compiler and the avrdude uploading tool. The Arduino IDE preference contains verbosity options that have the effect of printing the commands that are run while the program is compiled and uploaded. This was very useful to understand what the graphical user interface is doing, which turns out is a common workflow for C and C++ builds. The Figure 2-14 shows the “tool-chain” flow from writing C code to uploading to Arduino board.

![Figure 2-14 Tool-chain flow from c code to uploading to Arduino](image-url)
3.4 Raspberry PI

The Raspberry Pi is a low cost, credit card sized computer that plugs into a monitor and uses a standard keyboard and mouse. It is capable of doing everything you would expect a desktop computer to do, from browsing the internet and playing high-definition video, to making spreadsheets, word-processing, and playing games. Raspberry Pi is an ARM cortex based board designed for Electronic Engineers. It is a single board computer working on low power. With the processing speed and memory, Raspberry Pi can be used for performing different functions at a time, like a normal PC, and hence it is called Mini Computer. What’s more, the Raspberry Pi has the ability to interact with the outside world, and has been used in a wide array of digital maker projects, from music machines and parent detectors to weather stations and tweeting birdhouses with infrared cameras. Figure 2-15 shows RPi2.

![Figure 2-15 Raspberry Pi 2 model B](image)

3.4.1 Specifications and performance

As for the specifications, the Raspberry Pi is a credit card-sized computer powered by the Broadcom BCM2836 system-on-a-chip (SoC). This SoC includes a 32-bit ARM7 Quad Core processor, clocked at 900MHz, and a Videocore IV GPU. It also has 1GB of RAM in a POP package above the SoC [17]. The Raspberry Pi is powered by a 5V micro USB AC charger. There are different types of Raspberry Pi boards in the market now, the Raspberry Pi 2 Model B is the one used in this project.

Raspberry Pi has four USB 2.0 ports. These ports can be connected with any USB devices, like mouse and keyboard. It has also one Ethernet port. This port is for internet
connectivity or to transfer data to another device like a PC. It has a 3.5mm jack port for connecting headphones. PI has a single HDMI port for connecting a LCD/LED screen.

There is a micro USB port on the board, it provides power for the complete board.

### 3.4.2 Operating system and programming languages

The Raspberry Pi primarily uses Linux-kernel-based operating systems. The supported operating system is Raspbian, although it is compatible with many others. The current release of Ubuntu supports the Raspberry Pi 2, while Ubuntu and several popular versions of Linux, do not support the older Raspberry Pi 1 that runs on the ARM11. Raspberry Pi 2 can also run the Windows 10 IoT Core operating system, while no version of the Pi can run traditional Windows.

In the short time that the Raspberry Pi has been around, a considerable number of programming languages have been adapted for the Raspberry Pi, either by the creator of the language, who wanted to support the Pi by porting their creation, or by enthusiastic users who wanted to see their language of choice available on their platform of choice. Programming is done in multiple languages like C++, Java, Python, Html5, Perl, Erlang, bash scripting etc with Pi. In this project we used python and Javascript (using Nodejs as server side platform) with Bootstrap framework.

### 3.5 Communications

In order for the CNC to process any design implanted into it, the machine (motion controller that is Arduino board) must have a connection system between itself and the software being used by the CNC controller (Raspberry Pi 2). Many connections used today are very common to people from using cable linking to add pictures to their computer hard drive or using a modem connection to log on to the internet. Two major types of communication systems between controllers and other hardware are discussed.

#### 3.5.1 USB Ports

The USB ports, or universal serial bus ports, are most likely the simplest and one of the most widely available connection systems between computers and devices. The cable connector between the device and the computer uses either an “A” connector which travels upstream to the computer or a “B” connector which travels downstream to the device as shown in Figures 2-16 and 2-17.
The Raspberry pi will act as the host once the connection is made. The Arduino UNO board used in this project has a FTDI FT232RL USB/Serial chip embedded in the head of it.

The FT232R is the latest device to be added to FTDI’s range of USB UART interface Integrated Circuit Devices. The FT232R is a USB to serial UART interface with optional clock generator output, and the new FTDIChip-ID™ security dongle feature. In addition, asynchronous and synchronous bit bang interface modes are available. USB to serial designs using the FT232R have been further simplified by fully integrating the external EEPROM, clock circuit and USB resistors onto the device. The FT232R is fully compliant with the USB 2.0 specification and has been given the USB-IF Test-ID [18].

### 3.5.2 Ethernet

Ethernet is used greatly for networking over either short or long distances to many different devices and large amounts of information. It has a great advantage over other communication systems by allowing it to communicate with many devices at one time and many different levels of distance. There are two major types of Ethernet networks, LAN (local area networks) and WAN (wide area network). LAN’s are used to connect many devices over short distances while WAN’s are used to connect a few devices over large area of up to many kilometers. Although WAN’s carry information over long distances, they tend to be slower and less reliable than LAN’s, but improvements in fiber optic cables may lessen this hindrance as the process improves. Ethernet is able to accommodate new devices once they become attached to the network by connecting to the single cable, which allows any device on the network to communicate with any other device without modifications to the devices. Unfortunately, for the devices to communicate effectively with each other, they must have knowledge of the network’s protocol or language. The messages between the machines...
are sent over mediums that may meet at a shared medium or segment. The devices will interact with the segment by attaching at its nodes with the nodes communicating in chunks of information called frames [18].

4. Program of instruction

When starting out with CNC, the first thing to do is creating some sort of model, drawing, or representation of the part or object to be machined. Most of the time this is a function of a CAD/CAM systems so they will generate g-code (machine commands).

Computer-aided design (CAD) involves creating computer models defined by geometrical parameters. These models typically appear on a computer monitor as a three-dimensional representation of a part or a system of parts, which can be readily altered by changing relevant parameters. CAD systems enable designers to view objects under a wide variety of representations and to test these objects by simulating real-world conditions.

Computer-aided manufacturing (CAM) uses geometrical design data to control automated machinery. CAM systems are associated with computer numerical control (CNC) or direct numerical control (DNC) systems.

Figure 2-18 shows the steps needed for generating a g-code.

**Figure 2-18 CAD/CAM workflow.**
4.1 G-CODE

G-Code or Geometric Code is the generic name for a control language for CNC machines. It is a way to tell the machine to move to various points at a desired speed, control the spindle speed, turn on and off various coolants, and all sorts of other things. It is fairly standard, and is a useful tool. The standard version of G-code is known as RS-274D. Since G-codes are preparatory codes, in a CNC program they begin with the letter *G* and direct the machine [19]. Typical actions G-code directs include:

- Changing a pallet
- Rapid movement
- A series of controlled feed moves, resulting in a workpiece cut, a bored hole, or a decorative profile shape
- Controlling feed movement, in an arc or a straight line
- Setting tool information

4.2 How G-Code Works

In order to achieve these particular kinds of movement, Numerical Control uses a block as its basic unit—when printed, it resembles a line of text. Each block carries one or more words (of sorts) each consisting of a letter—detailing the function to be performed—followed by a number that assigns value to the function. Currently, a block of input is limited to a maximum of 256 characters. Below are some common individual codes, that when combined, guide a machine’s movement.

- **G00:** Rapid positioning
  This code causes the machine to operate at a high speed.

- **G01:** Linear interpolation
  The machine will move in a straight line, performing the appropriate machining (milling, cutting, etc).

- **G02:** Circular/Helical Interpolation
  The machine will move clockwise in a circular or helical pattern, performing the appropriate machining process.

- **G03:** Circular/Helical Interpolation
  This code is the same as G02, but enables counterclockwise movement.

- **G17:** X-Y plane selection
- **G18:** X-Z plane selection
• G19: Y-Z plane selection
  These codes maneuver the machine onto different planes for coordinated motion.
• G20: Programming in inches
• G21: Programming in mm
  Changes in programming units occur short-term with these particular codes.

The above codes are the same for both milling and turning, but other units may vary.

In terms of software specifications, most g-code files can be created using CAM, but certain CNC machines rely on “conversational” programming, which either hides or bypasses the use of g-code completely.

For more details you can check reference [20].

5. Conclusion

This chapter introduced the components used to construct a simple CNC router machine either from the mechanical side as the table, the frame and all the parts creating the CNC mechanism, or the software and electrical side where the Arduino and raspberry pi were introduced. Also, the control language for a CNC machine has been described.
CHAPTER THREE

CNC PROTOTYPE IMPLEMENTATION
1. Introduction

The main component of factory automation is the CNC which provides a set of functionalities for the management of machine tools. In this chapter, a low cost three dimensional computerized numerical control (CNC) router machine is constructed.

Our work is based on the new development in computer technology of low-cost open source hardware, the microcontroller Atmega328p Arduino based and the raspberry pi 2 model B. The final CNC machine will be controlled either locally by interacting with the Raspberry pi which is used as a replacement of a regular PC where a graphical user interface application was programmed, or remotely via network by connecting to the Raspberry pi which operates as a real-time web server.

2. CNC Prototype Architecture

Our system can be divided into three Sub-systems. As depicted in Figure3-1, Mechanical sub-system gets necessary control signals from electronics sub-system, which ultimately results in desired actuation of motors.

Electronics sub-system gets command or a set of commands from software sub-system and generates controls for mechanical Sub system.

Software Sub system which is Raspberry pi 2 model B in this project which provides easy to use interface for users which accepts ready g-code file or offers the CAD/CAM software to create new design and translates it to commands which will be used by machine  unit (the microcontroller Arduino ).

Dividing the system reduces dependency between hardware and software components and also allows us to modify any sub-system without affecting the rest of Sub systems.
Figure 3-1 General block diagram and hardware setup of CNC machine.
3. Mechanical Sub-System

The first idea was to build the frame of aluminum, but it turned out not to be possible because of budget restrictions. The frame was instead constructed out of a wood product. It contains stepper motors and gearing arrangement to produce required torque and wheels for moving axes. Three motors move along X, Y and Z axis respectively. Some components and parts were not available in the shops, so recycled parts from the old printer were used. Figure 3-2 shows the mechanical parts of the CNC machine assembled in our project.
Table 3-1 represents the dimensions of our CNC machine tool, which is very precious information for the programmer of the control unit to keep in mind the borders, so it will not be exceeded, also for g-code programmer where it is obligatory information. You cannot manufacture an object from a machine you don’t know its limits (Hardware or software).

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X axis travel</td>
<td>34 cm</td>
</tr>
<tr>
<td>Y axis travel</td>
<td>30 cm</td>
</tr>
<tr>
<td>Z axis travel</td>
<td>10 cm</td>
</tr>
<tr>
<td>CNC height</td>
<td>32 cm</td>
</tr>
<tr>
<td>CNC length</td>
<td>90 cm</td>
</tr>
<tr>
<td>CNC width</td>
<td>54 cm</td>
</tr>
</tbody>
</table>

Table 3-1 Dimensions of the CNC prototype

4. Electronic Sub-System

Electronics system is responsible for generating control signal to the stepper motors which guides the motion of tool path in each direction or axis. It consists of several units.

4.1 Power supply

Power supply is heart of the CNC system which converts the AC voltage to DC voltage and supplies required voltages to the corresponding devices. In this project, four AC/DC adapters were used. Three of them for powering stepper motors through their drivers (5V – 400mA) and the fourth one to power the Raspberry pi 2 model B (5V – 2A).

4.2 Motors

As it is known, the stepper motor is a brushless, synchronous electric motor that converts digital pulses into mechanical shaft rotation. The motor's position can then be controlled to move and hold at one of these steps without any feedback sensor (an open-loop controller). In our project, when working with a motor, a few steps need to be taken to get it moving correctly (calculation and calibration).
• Get the number of steps per revolution (by knowing the angle of the motor)
• Decide on micro-stepping value (depends on the motor driver specifications)
• Calculate steps per mm
• Move the carriage for a known distance
• Measure error and apply to settings

First, initial steps/mm is calculated. This step will not be necessary if using a mill with known geometries, just take the steps/mm as given in datasheet. But as in our project, if using recycled parts or variable materials (like belts), some basic math is needed to get an approximate first-calculation. This step should be done for each axis.

While turning the motor, measure the distance traveled in mm. Then, calculate steps per mm based on

\[
\text{steps per millimeter} = \frac{\text{Steps per revolution}}{\text{mm per revolution} \times \text{micro-stepping fraction}}
\]  

(3.1)

For example, we used a stepper motor with a 200 steps/rev, that is, a stepper motor with 1.8° step. It travels 42mm per revolution when operated with 1/8 micro-stepping.

\[
\text{steps per millimeter} = \frac{200}{42} \times \frac{1}{8} = 38.09 \frac{\text{steps}}{\text{mm}}
\]

The program in the microcontroller instructs the head of CNC (spindle) to move 2 cm (or some number of millimeters) where the number of steps is 761.9 (20*39.09). If closed, reset the head, mark the location and repeat. Make a measurement of the true movement.

Finally, modify the original calculation (initial steps/mm) by a ratio of the expected and measured movement. Another way to think of it is what is the percent error?

\[
\text{calculation}_{\text{new}} = \text{calculation}_{\text{initial}} \times \frac{\text{distance}_{\text{traveled}}}{\text{distance}_{\text{measured}}}
\]  

(3.2)

For our project, we intended to drive 20 cm but actually drove 23 cm. We take the original setting of 38.09, multiply by 20/23 to get 33.12. After programming the new setting, the movement is dead-on.
4.3 Stepper motor driver board

The stepper motor driver receives step and direction signals from the microcontroller and converts them into rated high voltage electrical signals to run the stepper motor. The single-axis TB6560 stepper motor driver is used for each axis of motion. These boards were used in our project so that in the case of motor drive problems the single boards can be swapped out, without the trouble of replacing an entire multi-axis driver board.

The terminal connections were made by connecting the corresponding pins from the driver with the microcontroller (Arduino). The DC power supply is connected between +24V and Ground, and the motor Phase A-B windings are connected between A+ and A-, B+ and B-. The CLK+ and CW+ of each axis are connected to the Arduino as illustrated in Figure 3-1. Figure 3.1 also showed the pins assigned for axis pulse signal and direction signal. The CLK-, CW- and EN pins are connected to ground.

4.4 Microcontroller board

Atmega328p Arduino based microcontroller development board is chosen here to control the motion of the system. It acts as brain of the CNC system which receives the commands in the g-code form from the software system which is the Raspberry Pi 2 model B connected through the USB/serial port with baud rate of 115200 bit per second.

Arduino development board is flashed with g-code interpreter, a code which is written in C language based on the NIST RS274NGC interpreter version 3 [21]. This code is responsible to generate the control signal for corresponding input from the software system (Raspberry Pi) to the stepper motors that directly controls the motion of the machine tool. Figure 3-3 represents the flowchart of the Arduino firmware. It describes the operation of the process and helps to understand the main work of the program very easily.
Figure 3-3 Flowchart of the firmware
The firmware of the microcontroller runs all the time this is why there is no end in the flowchart since the program will never reach the return function.

Almost all the information about the CNC work settings are stored in the EEPROM and updated at a small change. The status of the machine indicates the state of the machine where it can be IDLE, RUNING, HOLD or ALARM (abort). Knowing the previous state of the machine before taking any further actions is very important; e.g. if there was an ALARM then a power off for some reason, it would indicate after powering the system again that it was in ALARM status and should be fixed (kill the alarm), this is why these data are stored in the EEPROM. The current position indicates where the spindle or the head of the CNC machine is.

### 4.5 Raspberry Pi and the software development

The process of walking through various programs is known as a tool chain. The Figure 3-4 shows each distinct part of the CNC tool chain.

The solid modeling, design work, and CAD/CAM software are not in the scope of our project, and from here on it is assumed that the user have some g-code file from somewhere.

![CNC Tool Chain](image)

**Figure 3-4** CNC tool chain
4.5.1 Raspberry Pi with CNC machine

Most of modern CNC machines have HMI panel control. It provides a graphics-based visualization of the industrial control and monitoring system, it typically resides in a computer that communicates with a specialized such as a programmable automation controller (PAC), programmable logic controller (PLC) or distributed control system (DCS) or microcontrollers in the plant.

In our project, we used the Raspberry pi to host the HMI control system where we used the python programming language to program it using Tkinter as GUI library and PySerial library to communicate with the microcontroller.

Also, the Raspberry pi acts as a web server since we have created a real-time web application that performs HMI control system job but with remote access (via network).

4.5.2 Raspberry Pi Operating System

The raspberry pi 2 was announced in 2015 with a 900 MHz quad core Broadcom processor and 1 GByte of RAM. The performance is evident. It boots fast, with (almost) no lags, and smoother video performance.

Raspbian is the official OS for raspberry pi and is quite an experience on the pi 2. It is a port of the popular Linux operating system, Debian whezzy. It is the one used in our project.

To install Raspbian OS, an SD card of 8 GByte was used so it will be flashed using a program called “win32Diskimager” in windows. Once the write is complete, the SD card was ejected and inserted into the Raspberry Pi slot. After booting the Pi, the user credentials username and password will be asked. Raspberry Pi comes with a default user name and password which should be modified later for security reasons.

User : pi
Pass : raspberry

4.5.3 Pyserial, Tkinter and Nodejs

Since the Raspbian OS is a Linux based operating system than python environment is provided with it. But the libraries needed to create our GUI application (g-code) sender are not available, so we have installed them using Linux command line with internet connection availability.
To install the two python packages needed PySerial which is a module that encapsulates the access for the serial port (communication between Arduino and Raspberry Pi), and Tkinter which is Python's standard GUI (Graphical User Interface) package which is used to program the g-code sender.

```
root# sudo apt-get install python-pyserial
root# sudo apt-get install python-tk
```

For network control of raspberry pi, we installed a platform for developing server-side web application and deploying it. We used Nodejs which is Javascript runtime environment that processes incoming requests in real-time. JavaScript is a language that runs inside web browsers as part of documents loaded by the browser. It gives behavior to web pages where HTML gives semantic structure and CSS gives form or look and feel. Node.js is simple platform with some libraries to do I/O and networking, so that JavaScript code runs outside of the browser as creating shell scripts, backend services or connecting to hardware. It has an event-driven architecture capable of asynchronous I/O. These design choices aim to optimize throughput and scalability in Web applications with many input/output operations, as well as for real-time Web applications (e.g., real-time communication programs and browser games). To install it, type.

```
root# wget http://node-arm.herokuapp.com/node_latest_armhf.deb
root# sudo dpkg -i node_latest_armhf.deb
```

### 4.5.4 GUI G-CODE Sender Application

For our project, we have developed a front end user application to simplify the process of sending g-code to the microcontroller Arduino. Figure 3-5 and Figure 3-6 shows clearly the output window of the program that we have developed using Python, where it contains the important actions that makes the CNC machine easy and simple to be controlled. We call it “IGEECNC”.

“IGEECNC” was built using python programming language, it reads the g-code file opened by the user while interacting with the GUI (Graphical user interface), then it displays the path or the output that should be machined by the CNC. It waits for an event (mouse click) which is linked or binded with a button. If a start button was pressed, then it starts sending data line by line to the microcontroller through the USB/serial port, while the movement emulation in the canvas (Tkinter GUI widget) shows the progress of the work in the screen (monitor).
Figure 3.5 “igeeCNC” g-code sender control window

Figure 3.6 “igeeCNC” g-code sender manual/terminal window
Figure 3-7 explains for us the execution of the GUI application in general. It describes the flow from creating the GUI components and binding them with events to the quit event occurrence.

![Global flow chart of the GUI application](image)

**Figure 3-7** Global flow chart of the GUI application

### 4.5.5 Remote Control via Network

Nowadays, Remote control is an integral part in industry. This is why we added remote control for our project since the raspberry pi is a powerful single board computer that can easily handle local operation while running a daemon of Node.js (HTTP web server platform).

First, the ethernet interface of the raspberry pi must be configured by assigning it a static ip address so it is known to the user before it connects to the network. Then we configure our server to use a specific port where our web application will be delivered. It is 8000 in our case. Finally, we programmed a simple front end web application using Bootstrap framework which is linked to a backend application programmed in Javascript based on Nodejs that is responsible for handling the requests and transferring g-code commands to the microcontroller. Also, it updates the web
front end with the state and position of the CNC machine since it communicates directly with the microcontroller.

Bootstrap framework is a collection of tools containing HTML and CSS-based design templates for typography, forms, buttons, navigation, and other interface components, as well as optional JavaScript extensions.

Figure 3-8 shows the front end main page of the web application we have made, it is loaded in Google Chrome browser running under Windows OS.

![Figure 3-8 Front end main page of the web application](image)

The advantage of the web application which is a browser-based is cross platform, which means it will run in any Operating System like Windows, Mac OS, *nix. The user just need a browser which almost operating systems provide.

In this project, it is also possible to connect to the raspberry pi remotely using SSH since it is installed with the Linux OS which will give access to the terminal of the Raspberry Pi.
4.6 Raspberry Pi Automation

Automation of the Raspberry pi means to customize the Linux so it will run scripts and programs just after the startup. To do this we have modified the necessary script by removing the two first line so the default gui application of Raspberry Pi will not start.

root# sudo nano .config/lxsession/LXDE-pi/autostart

```
python /home/pi/igeeCnc/igeeCnc.py &
forever start igeeCncWeb/server.js
```

The `sudo` command used to edit the file with name `autostart` in root privileges with the text editor GNU nano in the directory `.config/lxsession/LXDE-pi`. The first added line will make the G-CODE sender window appear after staring up. The second will start the web server for the Nodejs.

5. Results and Discussions

Figure 3-9 shows the desired two object we tried to produce using our CNC while the Figure 3-10 shows the produced sketch by our CNC. The CAM we used to design and model them is CAMOTICS, it is an Open-Source software which creates and simulates a 3-axis CNC milling or engraving.

![Figure 3-9 The inputs created with CAMOTICS to CNC.](image)
The sample-1 was sent with g-code Sender (HMI), while the sample-2 was sent over network using the web application. The results show that our CNC is functional with low cost budget, but with a little inaccuracy in alignment which is due to errors in constructing the machine.

6. Conclusion:

In this chapter, the design and realization of a microcontroller based embedded three dimensional CNC machine was presented. Detailed descriptions of different modules along with technical details of their implementations have been given.

In this system, Python (with its libraries such as Tkinter and Pyserial) and Nodesjs have been used as a programming language on Raspbian OS which is a Linux-based. Two application have been developed, one acts as HMI panel control and the other is a web application that runs in a browser with cross platform feature.

The results of the CNC prototype have been also presented in this chapter and discussed.
General Conclusion

In this work, we got familiar with one of the famous industrial technology which is Computer Numerical Control. After a hard work for creating a working CNC prototype we have gained skills in electronics and software development as well as carpentry since we have built the mechanical part by ourselves.

In electrical part, we have studied the stepper motor mechanism, and its control theory, we used the TB-6560 stepper motor driver. These motors were very helpful in our project since they are easy to use because they are controlled with open loop control system.

In this work, we have learned the microcontroller programming with the C language using the IDE. Also, we got experience with the USB/Serial and how to communicate the microcontroller with the Raspberry pi which had a great impact on us on this project. Thanks to this small single board computer Raspberry Pi we have discovered the power of the Linux operating system which seems very useful and helpful for engineers and programmers since it offers a handy environment.

Beside that, we acquired the knowledge of the Python programming language to develop a Graphical User Interface applications that runs under Raspbian OS (Linux-based) to stream the g-code file to the microcontroller. Also, we learned how to program in Node.js environment and deploy the web application we developed using the bootstrap framework to be accessible via network.

The results produced by our CNC are satisfactory after such a hard work; we finally got good result with a huge treasure of knowledge and skills in electronics and software development.

As further work, we propose to use servo or DC motors instead of stepper motors that provide more precision. Also, for safe work, it is better to make limit switches at the end of each axis and try to use some sort of sophisticated spindle.
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