Sudan University of Science and Technology

College of Graduate Studies

Design and Implementation of Printed Circuit Board Computer Numerical Control Machine with Path Planning Algorithm

تصميم وتصنيع ماكينة طباعة اللوحات الإلكترونية ذات التحكم الرقمي الحاسوبي مع خوارزمية تخطيط المسار

Thesis Submitted in Partial Fulfillment to the Requirements for the Degree of Master of Science in Electrical Engineering (Control and Microprocessor)

Presented By:

MUSTAFA ELZAIN HAMAD BALLA

Supervised by:

Dr. OMER ABDEL RAZAG SHARIF ABUBAKER

June 2018

الآية

بسم الله الرحمن الرحيم

﴿رَبَّنَا إِنَّنَا سَمِعْنَا مُنَادِيًا يُنَادِي لِلْإِيمَانِ أَنْ آمِنُوا بِرَبِّكُمْ فَآمَنَّا ۚ رَبَّنَا فَاغْفِرْ لَنَا ذُنُوبَنَا وَكَفِّرْ عَنَّا سَيِّئَاتِنَا وَتَوَفَّنَا مَعَ الْأَبْرَارِ ۝ رَبَّنَا وَآتِنَا مَاوَعَدتَّنَا عَلَىٰ رُسُلِكَ وَلَا تُخْزِنَا يَوْمَ الْقِيَامَةِ ۗ إِنَّكَ لَا تُخْلِفُ الْمِيعَادَ ۝﴾

سورة آل عمران الآيات 193-194.

DEDICATION

This research is dedicated to:

- The sake of Allah, my creator and my master.
- My great teacher and messenger, Mohammed (May Allah bless and great him).
- My great parents, who never stop giving of themselves in countless ways.
- My dearest wife, who leads me through the valley of darkness with light of hope and support.
- My beloved brothers and sisters, who stand by me when things look bleak.
- My beautiful princesses Muzan, Ludan, Mina, Lieen, Juan, Miar, Maab, Fatima Alzahra.
- My Supper Heroes Mohammed Ahmed, Mustafa, Mohammed Shehab, Mohammed Mustafa, Mohammed Abdlrahim, Elzain and to all of my family, the symbol of love and giving.
- My friends for their encourage and support.
- All the people in my life who touch my heart.

ACKNOWLEDGMENT

All praises be to Allah for blessing myself with opportunities abound and showering upon me HIS mercy and guidance all through the life. I am praying that He continues the same the rest of my life.

First and foremost I would like to express my gratitude to my Supervisor Dr: Omer Abdelrazag Sharif, for guiding and helping throughout this project work, I consider myself extremely fortunate for having the opportunity to learn and work under his supervision over the entire period.

Also I would like to take this opportunity to thank my friends and colleagues especially Eng. Muaaz Abdlrahim, Eng. Muhanad Mutasim and Eng. Akram Mohammed for their true help through this project.

All thanks due to my family members especially my father, mother, wife, sisters, and brothers for their prayers, patient and encourage which have helped me in becoming what I am today.

ABSTRACT

A Printed Circuit Board (PCB) Mill is a device that etches out a pattern on a copper clad board such that it makes a PCB. PCBs are used everywhere in the field of electrical engineering to connect electrical components to one another. This research presents the design and implementation of low-cost mini PCB commuter numerical control machine based on microcontroller. A stepper motors were used to compile the movement of the three axes coordinates. Moreover, the generated Gerber file was analyzed using MATLAB platform where the analyzed file is converted to C-code and transmitted to the milling and drilling machine through the serial communication port using RS232 protocol. In addition, a path planning technique based on sorting drilling algorithm was also proposed. The simulated and implemented results were coincided.

المستخلص

جهاز طباعة اللوحات الإلكترونية عبارة عن جهاز يقوم بإزالة بعض الأجزاء النحاسية في اللوح النحاسي تبعا نمط معين لتشكيل الدائرة الإلكترونية المطبوعة. تستخدم الدوائر الإلكترونية المطبوعة في جميع مجالات الهندسة الكهربائية لتوفر الروابط الكهربية للمكونات الإلكترونية. في هذا البحث تم تصميم وتصنيع ماكينة صغيرة لطباعة اللوحات الإلكترونية ذات التحكم الرقمي الحاسوبي قليلة التكلفة بإستخدام المتحكمات الدقيقة. تم إستخدام محركات الخطوة لترجمة حركة المحاور الثلاثية للماكينة عبر إيعازات الإحداثيات. الملف الحاسوبي المتولد نتيجة لتصميم الدائرة الإلكترونية تم تحليلة بإستخدام برنامج مطور في بيئة الماتلاب وإرسال التحليل للمتحكم الدقيق خاصة جهاز طباعة الدوائر الإلكترونية عبر المنفذ التساسلي. بالإضافة لتصميم وتصنيع جهاز الطباعة من المواد المعاد إستخدامها كسواقات الأقراص المضغوطة، تم تطوير خوارزمية تخطيط المسار عبر ترتيب نقاط التخريم للمحورالصادي. تم الحصول على نتائج جيدة في حالتي النمذجة والتنفيذ.

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LIST OF ABBREVIATIONS

NC	Numerical Control
CNC	Computer Numerical Control
MCU	Machine Control Unit
MIT	Massachusetts Institute of Technology
DC	Direct Current
PCB	Printed Circuit Board
QFT	Quality Function Board
GUI	Graphic User Interface
CD	Compact Disk
DVD	Digital Video Disk
TSP	Travel Saleman Problem
PC	Personal Computer
USB	Universal Serial Bus
RAM	Random Access Memory
ROM	Read Only Memory
EEPROM	Erasable Electrical Programmable Memory
SPRAM	Static Random Access Memory
JTAC	Joint Terminal Attack Controller
USART	Universal Asynchronous Receiver Transmitter
ADC	Analog to Digital Converter
SPI	Serial Peripheral Interface
ISP	Internet Service Provider
AVR	Advanced Virtual Risc
RISC	Reduced Instruction Set Computer
NEMA	National Electrical Manufacturers Association

PID	Proportional Integral Derivative
RPM	Repletion Per Meter
AC	Alternating Current
MATLAB	Matrix And Laboratory
COM	COMmunication
GPS	Global Position System
GSM	Global System for Mobile
MAX232	MAXimum 232
TXD	Transmit Data
RXD	Receiving Data
RTS	Request to Send
CTS	Clear to Send
DSR	Data Set Ready
DTR	Data Terminal Ready
DCD	Data Carrier Detec
RI	Right Indicator
GND	Grounding
IC	Integrated Circuit
TTL	Transistor-Transistor Logic
TIA	Telecommunication Industry Association
EAGLE	Easily Applicable Graphic Layout Editor
EDA	Electronic Design Automation
CAD	Computer Aided Design
AOI	Automated Optical Inspection

CHAPTER ONE

INTRODUCTION

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INTRODUCTION

1.1 General concept

A printed circuit board (PCB) can be defined as a mechanically supports and electrically connects electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate. Components (e.g. capacitors, resistors or active devices) are generally soldered on the PCB. Advanced PCBs may contain components embedded in the substrate. PCBs can be single sided (one copper layer), double sided (two copper layers) or multi-layer (outer and inner layers). Conductors on different layers are connected with vias. Multi-layer PCBs allow for much higher component density. PCBs may be classified in many different ways according to their various attributes. One fundamental structure common to all of them is that they must provide electrical conductor paths that interconnect components to be mounted on them. There are two basic ways to form these conductors:

i. Subtractive: where the unwanted portion of the copper foil on the base substrate is etched away, leaving the desired conductor pattern in place.
ii. Additive: where the formation of the conductor pattern is accomplished by adding copper to a bare (no copper foil) substrate in the pattern and places desired. This can be done by plating copper, screening conductive paste, or laying down insulating wire onto the substrate on the predetermined conductor paths.

There are Different methods to make subtractive PCBs such as etching. Etching is probably the easiest and most cost effective process where it can be chemically (i.e. Ferric Chloride*FeCl3*) or mechanically (i.e. using Numerical Control (NC) or Computer Numerical Control (CNC) milling system) in removing the unwanted copper from a plated board. It must use a mask or resist on the portions of the copper that wanted to be remained after the etching. These portions that remain on the board are the traces that carry electrical current between devices. More specifically in NC system the PCB file of computer is converted to whole data file which is then converted to the form of data appropriate for the microcontroller (MC). This data and the monitor program are loaded into MC flash memory. The control of the milling machine is from the MC not from the computer. When the PCB pattern should change, and then the new PCB file is downloaded to the memory again.

On other hand in CNC system the computer directly controls the milling machine and receives feedbacks from it. The MC is still useful. The computer displays X-Y coordinates of the mill and several other operation states. It is worthy to mention that the CNC machine has some disadvantages such as: Costly setup, need skilled operators, Computers& programming knowledge required, require special working environment and specialized maintenance course.

1.2 Problem Statement

Manually PCB milling and drilling need both precision and patience. Often, the repetitiveness of that task leads to countless frustration efficiency in mass scale production. Also lead to lose man power full.

Most of the previous studies explained the design of milling PCB machine with different ways for various purposes where some addressed the challenge of automatic holing different algorithms such as Row-by-row and path planning.

Local design and implementation of milling and drilling PCB will decrease the manufacture cost, delivery time and after sales services especially for SMEs and institutes.

1.3 Objectives

The objectives of this research are to:

i. Design and implementation of a low cost PCB machine with path planning algorithm.

ii. Design and implementation of the interfacing circuit with computer, microcontroller circuits as well as human machine.

1.4 Methodology

To achieve the previous objectives, the following methodology applied to the proposed system in Figure 1.1:

- ✓ Design and implement MATLAB-based program to receive the generated PCB art work/ Image to generate the G-code as well as determine the holing position.
  - o The holing position can be holed using combination of Row by row technique and Travel Sale-man Problem (TSP).
- ✓ Design and implement a G-code to C-code converter using MATLAB or other programm such as FlatCam to let the microcontroller achieve the milling and holing mission.
- ✓ Design, simulate and implement an interface unit between the Personal Computer (PC) and the microcontroller using either RS232 or Universal Serial Bus (USB) interface.
- ✓ Design, simulate and implement of the suitable drivers for the X, Y, Z axis stepper motors. The designed drivers /motors can be interfaced to the suitable selected microcontroller.
- ✓ The suitable mechanical parts are selected for the CNC machine and integrate it with the control parts.
- ✓ All parts was tested individually and the whole system for optimization.

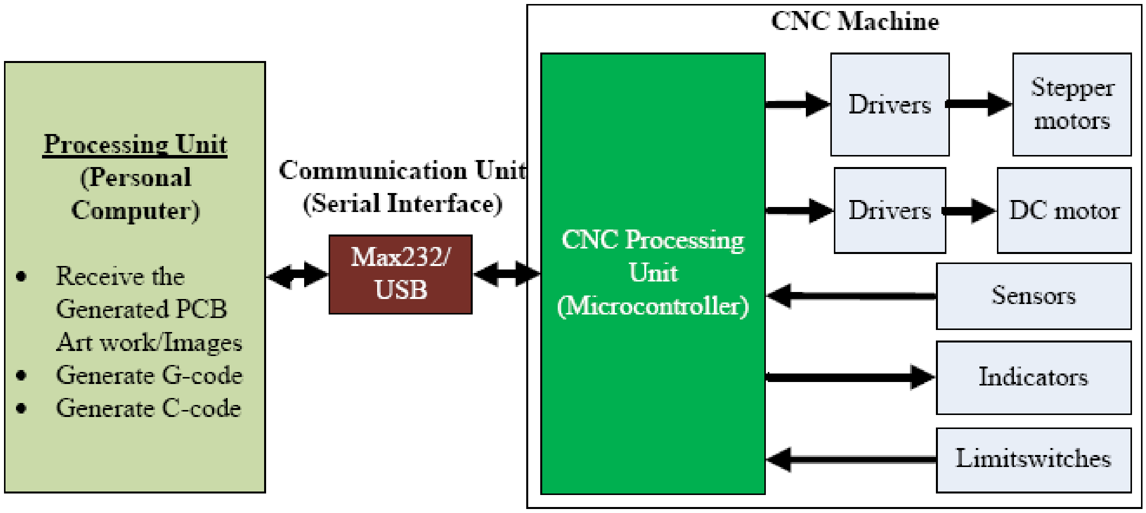

Figure 1.1: The proposed PCB machine block diagram

1.5 Thesis Outline

Including Chapter one, chapter two includes literature review and theoretical background of the conducted research area. In chapter three, the proposed system was design and implemented using MATLAB platform and Proteus ISIS simulator. The obtained results were presented and discussed in chapter four. A conclusion and future work were drawn in chapter five.

CHAPTER TWO

BACKGROUND AND LITERATURE REVIEW

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BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

Numerical control is the operation of a machine tool by a series of coded instructions consisting of numbers, letters of the alphabet, and symbols that the Machine Control Unit (MCU) can understand. These instructions are changed into electrical pulses of current that the machine's motors and controls follow to carry out manufacturing operations on a workpiece. The numbers, letters, and symbols are coded instructions that refer to specific distances, positions, functions, or motions, that the machine tool can understand as it machines the workpiece.

2.2 History of NC

In 1947, the U.S. Air Force found that the complex designs and shapes of aircraft parts such as helicopter rotor blades and missile components were causing problems for manufacturers, who could not keep up to projected production schedules. At that time, John Parsons, of the Parsons Corporation, of Traverse City, Michigan, began experimenting with the idea of making a machine tool generate a “thru-axis curve" by using numerical data to control the machine tool motions. In 1949, the U.S. Air Material Command awarded Parsons a contract to develop NC and in turn speed up production methods. Parsons subcontracted this study to the servomechanism laboratory of the Massachusetts Institute of Technology (MIT), which in 1952 successfully demonstrated a vertical spindle Cincinnati Hydrotel, which made parts through simultaneous three-axis cutting tool movements. In a very short period of time, almost all machine tool manufacturers were producing machines with NC.

At the 1960 machine tool show in Chicago, over a hundred NC machines were displayed. Most of these machines had relatively simple point-to-point positioning, but the principle of NC was now firmly established. From this point, NC improved rapidly as the electronics industry developed new products (Figure 2.1). At first, miniature electronic tubes were developed, but the controls were big, bulky, and not very reliable. Then solid-state circuitry and, eventually, modular, or integrated circuits were developed. The control unit became smaller, more reliable, and less expensive. The development of even better machine tools and control units helped spread the use of NC from the machine tool industry to all facets of manufacturing.

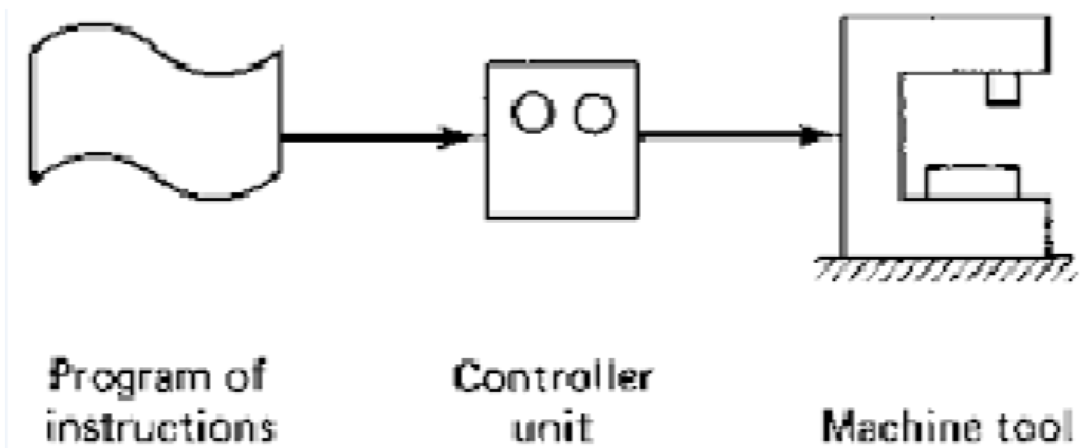


Figure 2.1: NC Components

2.3 NC Evolve into CNC

The introduction of software-based controls in the early 1970s replaced the NC hardware design with complete computer logic that had more capacity and could be programmed for a variety of functions at any time. This made it possible to revise, modify, or update CNC programs or parts of programs at any time on a computer. In turn, CNC machines became easier to use with their menu-selected displays, advanced graphics, and ease of programming [1].

2.4 CNC Applications

The applications of CNC include both for machine tool as well as non-machine tool area. In the machine tool category, CNC is widely used for lathe, drill press, milling machine, grinding unit, laser, sheet-metal press working machine, tube bending machine etc. Highly automated machine tools such as turning center and machining center which change the cutting tools automatically under CNC control have been developed. In the non-machine tool category, CNC applications include welding machines, coordinate measuring machine, electronic assembly, tape laying filament winding machines for composites etc. The benefits of CNC are

- High accuracy in manufacturing.
- Short production time.
- Greater manufacturing flexibility.
- Simpler fix-Turning.
- Contour machining (2 to 5-axis machining).
- Reduce human error.

The drawbacks include high cost, maintenance, and the requirement of skilled part programmer. A CNC system consists of three basic components as in Figure (2.2):

- Machine tool (lathe, drill press, milling machine etc.).
- Part program.
- Machine control unit (MCU).

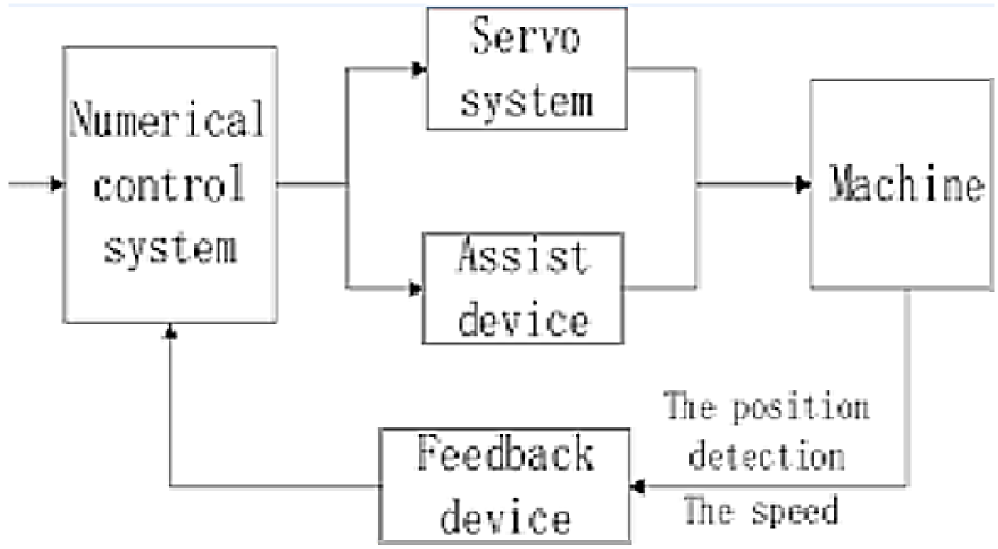


Figure 2.2: CNC Components

2.5 CNC Milling Machine

A CNC milling machine (Figure 2.3) is a computer controlled machine that can be used to make very precise parts. The machine works by removing material from the workpiece with a rotating cutting tool. The machine does this by guiding the tool in all three directions of the Cartesian coordinate system, that meaning along the X, Y and Z axis. The arrows in the figure 2.2 illustrate the three directions the CNC Mill can move in. The CNC Mill machine has many different materials; examples are steel, aluminum, brass, copper and plastic. A mill is not designed for cutting wood and should not be used for that. Examples of operations that can be made in a CNC Mill is to cut a profile shape, engrave text, mill a 3D surface, drill holes and mill bearing pockets[1].

Figure 2.3: CNC milling machine

2.6 CNC Drilling Machine

Drilling is the method of making holes in a work piece with metal cutting tools. Drilling is associated with machining operations such as trepanning, counter boring, reaming and boring. A main rotating movement is common to all these processes combined with a linear feed. There is a clear distinction between short hole and deep hole drilling. The drilling process can in some respects be compared with turning and milling but the demands on chip breaking and the evacuation of chips is critical in drilling. Machining is restricted by the hole dimensions, the greater the hole depth, the more demanding it is to control the process and to remove the chips. Short holes occur frequently on many components and high material removal rate is a growing priority along with quality and reliability.

- Solid drilling is the most common drilling method, where the hole is drilled in solid material to a predetermined diameter and in a single operation.
- Trepanning is principally used for larger hole diameters since this method is not so power-consuming as solid drilling. The trepanning never

machines the whole diameter, only a ring at the periphery. Instead of all the material being removed in the form of chips, a core is left round the center of the hole.

- Counter boring is the enlargement of an existing hole with a specifically designed tool. This machines away a substantial amount of material at the periphery of the hole.
- Reaming is the finishing of an existing hole. This method involves small working allowances to achieve high surface finish and close tolerances.

The cutting speed, or surface speed (vc) in for drilling is determined by the periphery speed and can be calculated from the spindle speed (n) which is expressed in number of revolutions per minute. During one revolution, the periphery of the drill will describe a circle with a circumference of π x Dc, where Dc is the tool diameter. The cutting speed also varies depending upon which cutting edge across the drill-face is being considered. A machining challenge for drilling tools is that from the periphery to the center of the drill, the cutting speed declines in value, to be zero at the center. Recommended cutting speeds are for the highest speed at the periphery.

The feed per revolution (fn) in mm/rev expresses the axial movement of the tool during one revolution and is used to calculate the penetration rate and to express the feed capability of the drill. The penetration rate or feed speed (*vf*) in mm/min is the feed of the tool in relation to the work piece expressed in length per unit time. This is known as the machine feed or table feed. The product of feed per revolution and spindle speed gives the rate at which the drill penetrates the work piece. The hole depth (L) is an important factor in drilling as is the radial cutting depth (*ap*) and feed per tooth (*fz*) for calculations [1]. Figure(2.4) shows the CNC drilling machine.

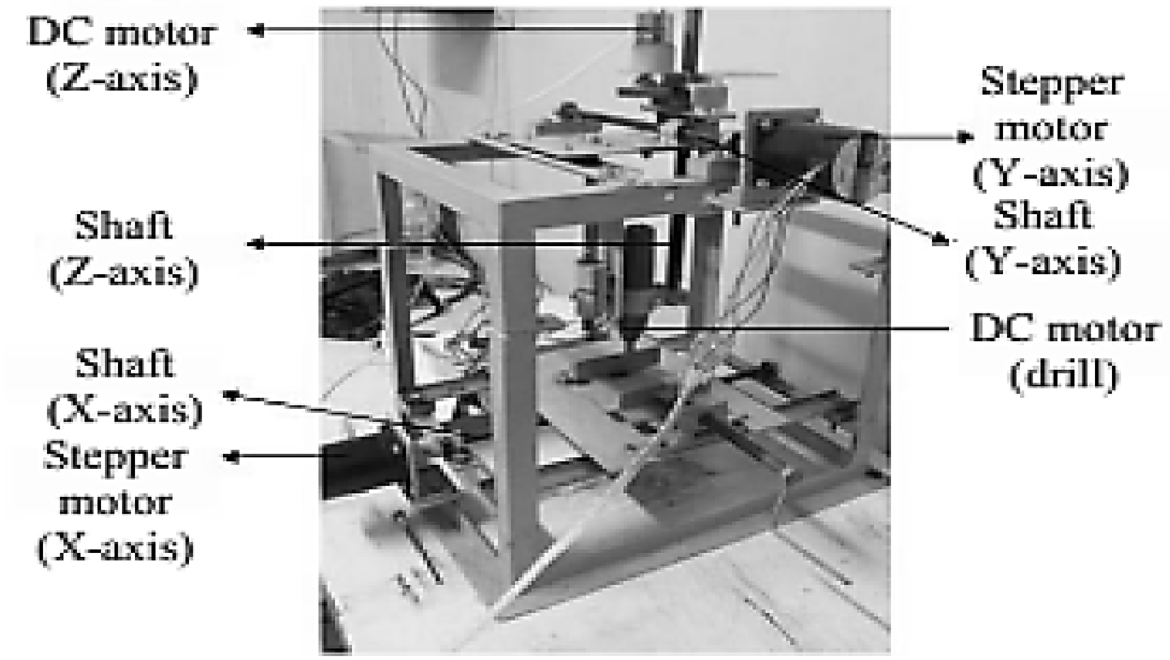


Figure 2.4: CNC drilling machine

2.7 Machining holes

Holes are either made or finish machined. Most work pieces have at least one hole and depending upon the function of the hole, it needs machining to various limitations. The main factors that characterize a hole from the machining view of point are: diameter, depth, quality, material, conditions, reliability, and productivity.

2.8 Printed Circuit Boards

Printed Circuit Board is used to mechanically support and electrically connect electronic components using conductive pathways, tracks original traces etched from copper sheets laminated onto a non-conductive substrate. Printed circuit boards manufactured now a days can be built using the following four items

- Copper-clad laminates.
- Resin impregnated B-stage cloth
- Copper foil.

- Laminates.

Majority of printed circuit boards are made from purchased laminate material with copper applied to both sides. The non-useful copper is removed by various methods leaving only the desired copper traces, this is called subtractive. Holes through a PCB are typically drilled with small-diameter drill bits made of solid coated tungsten carbide. Coated tungsten carbide is used since board materials are very abrasive and drilling must be done at high Repletion Per Meter (RPM) and high feed to be cost effective. Drill bits should remain sharp so as not to tear the traces. Drilling with HSS tool is simply not feasible since the drill bits will dull quickly and thus tear the copper and ruin the boards. The drilling operation done by automated drilling machines with placement controlled by a drill tape or drill file. These computer-generated files are also known as numerically controlled drill. These holes are often filled with annular rings (hollow rivets) to create vias. The Vias allow the electrical and thermal connection of conductors on opposite sides of the PCB [2]. Figure 2.5 gives an example of PCB.

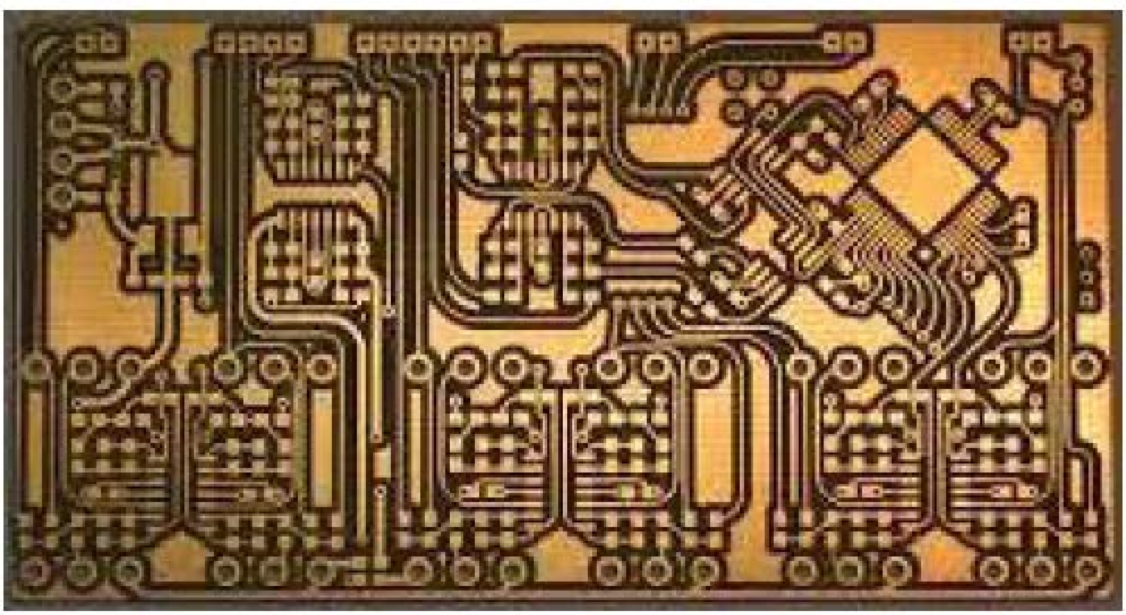


Figure (2.5) example of printed circuit board

2.9 Printed Circuit Board Milling

Printed circuit board milling machine (also: isolation milling) is the process of removing areas of copper from a sheet of printed circuit board material to recreate the pads, signal traces and structures according to patterns from a digital circuit board plan known as a layout file. Similar to the more common and well known chemical PCB etch process, the PCB milling process is subtractive: material is removed to create the electrical isolation and ground planes required. However, unlike the chemical etch process, PCB milling is typically a non-chemical process and as such it can be completed in a typical office or lab environment without exposure to hazardous chemicals. High quality circuit boards can be produced using either process. In the case of PCB milling, the quality of a circuit board is chiefly determined by the systems true, or weighted, milling accuracy and control as well as the condition (sharpness, temper) of the milling bits and their respective feed/rotational speeds. By contrast, in the chemical etch process; the quality of a circuit board depends on the accuracy and/or quality of the photo-masking and the state of the etching chemicals [3]. Figure (2.6) shows the PCB milling.

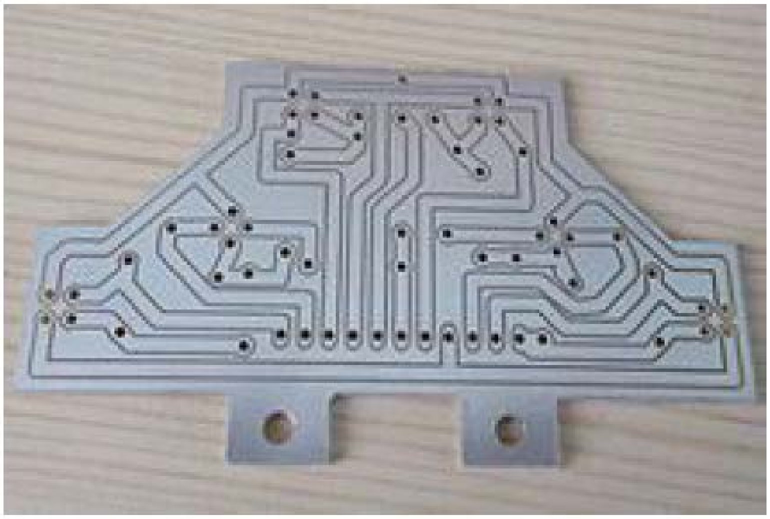


Figure 2.6: Printed circuit board milling

2.10 Drilling Printed Circuit Board

Creating holes on single or multilayer printed circuit boards (PCBs) is an important stage in electronic production. Holes of different sizes and at a large number of positions (up to thousands) must be drilled with high precision for manual or automatic insertion of various electronic devices and components. The PCB pattern of the circuit schematic diagram is extracted from a sample PCB using image processing techniques and stepper motors are used to move drill to the required position [4].

2.11 Related Literature of Path Planning Algorithm

Path planning algorithm can classify into a lot of methods such as row by row and nearest neighbor search method.

2.11.1 Row by row scanning method

In the this algorithm the pointer moves up along the y axis keeping the x coordinate zero from the smallest y coordinate in the array up to the largest. As it reaches each y coordinate the pointer will move along the x axis keeping the y coordinate constant until it reaches each point corresponding to that y coordinate. It will then return back to the y axis after it has covered all the points having that particular y coordinate. In this way the pointer will reach each point by moving sequential up the y axis and along the x axis much like a type writer [5].

2.11.2 Nearest neighbor search method

It is firstly proposed by Minsky and Papert in 1969 [6]. It has also been referred to as the post office problem, proximity search, closest point search, and best match file searching problem. The exact nearest neighbor search problem can be defined as: given a set of points P in an n-dimensional space S and a metric to determine the distance between any two points in S, how to most efficiently find the point in P which is nearest to an arbitrarily given query point q in S. A generalization of nearest neighbor search is the k-nearest-neighbor search in which k points in P nearest to an arbitrarily given query point q in S are found, where k can be 1, 2, ... Another common variant of the nearest neighbor search is a range search, which finds all points in P in S that are within a pre-defined range of arbitrary shape and with respect to an arbitrarily given query point q in S. 6 The space S can be a metric space or a non-metric space. The nearest neighbor search in a non-metric space sometimes can be converted into a nearest neighbor search in metric space. This thesis and the proposed methods here focus on the metric space and particularly on Euclidean space.

Ideally, an exact nearest neighbor or k exact nearest neighbors is being sought. In low dimensionality, an exact nearest neighbor search can be achieved in sub-linear or logarithmic time complexity. However, the computational complexity of an exact nearest neighbor search can increase exponentially as the dimensionality increases. This phenomenon has been referred as the curse of dimensionality. The efficiency of exact nearest neighbor search methods would degrade drastically as the dimensionality of space S increases. However, if approximate nearest neighbors are being sought, the computational complexity even in high dimensionality could remain polynomial. The approximate nearest neighbor search problem can be defined as: given a set of points P in n-dimensional space S and a metric to determine the distance between any two points in S, how to construct a data structure so that for an arbitrarily given query point q, it could most efficiently find all points whose distance to q is at most $(1 + \varepsilon)$ times the distance from q to its nearest point in P, where ε is a positive number. Locality-sensitive hashing, proposed by Piotr Indyk and Rajeev Motwani in 1998, is one of the earliest approximate nearest neighbor search methods overcoming the curse of dimensionality and has received arguably the most attention in practical contexts [5].

2.12 Previous Studies

Due to the small size of electronic components for developed product, consequently the printed circuit board used for it getting more complex and with thinner tracks. And due to the electromechanical corrosion does not produce good result. Basniak and Catapan [7] have designed and developed of a CNC milling machine for PCB with low manufacturing cost using Quality Function Development (QFD) matrix to obtain the customer requirement as well as morphological matrix to obtain all possible solution for requirement. And it was possible to develop the product with that requirement making very thin tracks in order of tenths millimeters. Basniak and Catapan [7] have mentioned that the main problem was the tool holder, which cannot hold the tool concentric in their design to the spindle axis (rupture of very thin tracks can happen).

CNC machine are capable of performing multiple operation simultaneously, due to this many manufacturing industries are adopting it to increase their production that Balasub and Prasanthi [8] have designed and developed one CNC machine that can be used for drilling the PCB for small scale industries with 8051 microcontroller. Unfortunately there is no drilling as well as depth control.

Due to the enormous contribution of PCB in electronic device industry. Mohammed *etal.* [9] have designed and implemented of a low cost and simple controlling system for CNC machine to mill and drill electronic diagrams on PCBs. Mohammed Abdullah *etal.* [9] have tried to make a adapt with the system accuracy with limit sensors, increasing the safety factor for users by providing a protected shield to the machine using Graphic User Interface (GUI) as operation monitor with control buttons supporting a real time feedback sensors.

Printing of the circuit to the copper board is most difficult task in PCB fabrication process and it tedious process in many techniques such as screen printing, laser printing or manual printing and each of it need high cost production, high requirement of man power, high time consuming. Anjalk *etal.* [10] have designed and implemented a robotic arm to plot the circuit on the copper board and makes retracing of the circuit from PCB possible using Arduino and it became easy to track a layout and plot it directly on a copper board by wireless robotic arm.

Because of low cost manufacture of PCB has become a basic need in electronic laboratories for electronic student and hobbyists. Mohamed-Kamaruzzaman *etal.* [11] have designed and implemented of an CNC plotter (drawing surface area 20cm*20cm) which will be able to draw a PCB layout (text or any image) on a solid surface using Arduino and some spare parts from printers and CD/DVD room. They designed it with very simple construction scheme and can be carried anywhere without much effort and the pen can be replaced with a pinhead or laser effort or any other tool for different purpose, with limitation on speed, excess head, displacement error and slight vibration.

To create holes on single or multilayer of different size and large number of positions with high precision, Nguyen Huu [12] has designed and built an automatic electro-mechanical PCB drilling machine based on AT89C51 ATMEL microcontroller which have configured as NC.

In order to develop a low cost PCB drilling machine for small scale industries to avoid workload of human, Noor-Farooque *etal.* [5] have designed Arduino-based PCB drilling machine using Row-by-Row path planning method to make the system more stable and accurate in combination of MATLAB.

To eliminate the need of manually enter the drill holes coordinate, Alwisetal. [13] have designed a path planning algorithm to minimize the length of drill travel. Acomprison between TSP (Travel Salesman Problem) and Row-by-Row algorithm have been made. The TSP algorithm uses a path planning algorithm performs the Row-by-Row as a normal navigation algorithm.

For particular, drilling PCB holes with a limited depth manually consumes a lot of time. Then Nirangan *etal.* [14] havedesigned and implement a microcontroller based system such that the drilling depth is controlled automatically to set value by potentiometer.

CHAPTER THREE

PROPOSED PCB CNC SYSTEM DESIGN AND IMPLEMENTATION

CHAPTER THREE

PROPOSED PCB CNC SYSTEM DESIGN AND IMPLEMENTATION

3.1. Introduction

In this chapter, the whole proposed system is viewed, designed, and implanted. The proposed system and its components are presented in Figure 3.1.

The milling machine which is the process of using rotary cutters to remove material from a workpiece by advancing (or feeding) the cutter into the workpiece at a certain direction. The CNC machine consists of: processing unit (microcontroller), three stepper motors with their drivers for the three axis movement, Direct Current DC for drilling operation, and limit switches and indicators for safety and easy operation recognition. The milling machine can communicate with the PC through serial interface (RS232/USB communication protocol) where the PCB artwork, Gerber file, G-code, and G-code to C-code are completed.

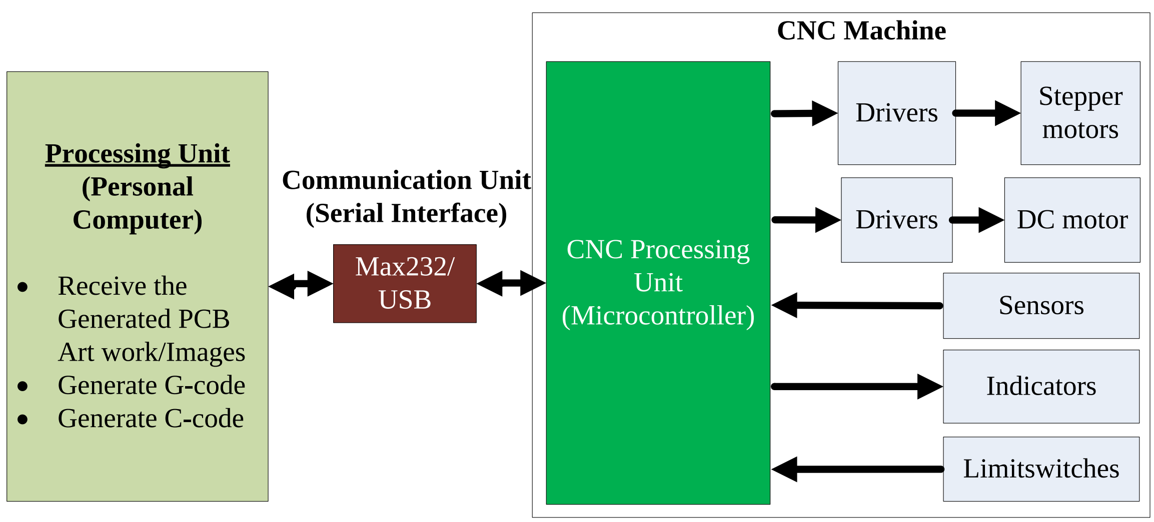


Figure 3.1: The proposed PCB machine block diagram

In the following, each system part is briefly discussed where the intra-connection between subsystem component is depicted.

3.2. CNC Machine Processing Unit

A microcontroller is a small computer on a single integrated circuit consisting internally of a relatively simple Central Processing Unit (CPU),serial communication, clock, timers, Input and Output(I/P) ports , BUS (address and data), memory units Random Access Memory (RAM) and Read Only Memory (ROM) and programmable. Microcontrollers contain a small amount of RAM so they are designed for small dedicated applications. Microcontrollers are used in automatically controlled devices such as control systems, office machines, automobile engines, power tools and many others. By reducing the size, cost and power consumption, microcontrollers makes it economical to electronically control many more processes. There are many programming languages used in microcontrollers, the main ones are Basic, C and assembly languages. Microcontrollers are generally harder to program than personal computers because it is not that simple to view debugging output, it takes more time to flash a new firmware and the tools used are generally less developed than PC tools. There are a large number of brands and types of microcontrollers in the market including, but not limited to Atmel, Microchip, Intel, Zilog, Toshiba, Rabbit [15]. Therefore, a suitable microcontroller for the proposed system must be justified selected. Because it is impractical to compare all of microcontroller feature for these different families, only some important features are compared in Table 3.1. For low cost, speed and availability, the ATMEL microcontroller is selected to be the processing unit for the proposed system.

Table 3.1: Comparison between difference microcontroller families

Atmel	Microchip	Rabbit	Intel
• wide availability • free software • debugger unit not required • serial programming capability, supports C, C++, Assembly • most familiar with use • lowest cost	• wide availability • extensive collection of application notes • debugger unit is costly • serial programming capability, supports C, C++, Assembly • un familiar with use • low cost	• high performance • free software • debugger unit not required • unfamiliar with use • expensive	• reliable brand • serial programming capability, supports C, C++, Assembly • unfamiliar with use • most expensive

- Atmega32 microcontroller

The ATmega32 provides the following features: 32Kbytes of in-system programmable flash program memory with read-while-write capabilities, 1024 bytes Erasable Electrical Programmable Read Only Memory (EEPROM), 2Kbyte SRAM, 32 general purpose I/O lines, 32 general purpose working registers, a Joint Terminal Attack Controller (JTAG) interface for boundary scan, on-chip debugging support and programming, three flexible timer/counters with compare modes, internal and external interrupts, a serial programmable Universal Asynchronous Receiver Transmitter (USART), a byte oriented two-wire Serial Interface, an 8-channel, 10-bit Analog to Digital Converer (ADC) with optional differential input stage with programmable gain, a programmable watchdog timer with internal oscillator, an Serial Peripheral Interface (SPI) serial port, and six software selectable power saving modes. The On chip Internet Service Provider (ISP) Flash allows the program memory to be reprogrammed in-system through an SPI serial interface, by a conventional non-volatile memory programmer, or by an on-chip Boot program running on the Advanced Virtual Risk (AVR) core. By combining an 8-bit Reduce Instruction Set Computer (RISC) CPU with in-system self-programmable flash on a monolithic chip, the Atmel ATmega32 is a powerful microcontroller that provides a highly-flexible and cost-effective solution to many embedded control applications. The Atmel AVR ATmega32 is supported with a full suite of program and system development tools including: C compilers, macro assemblers, program debugger/simulators, in-circuit emulators, and evaluation kit [16]. Figure 3.2 shows Atmega32 microcontroller.

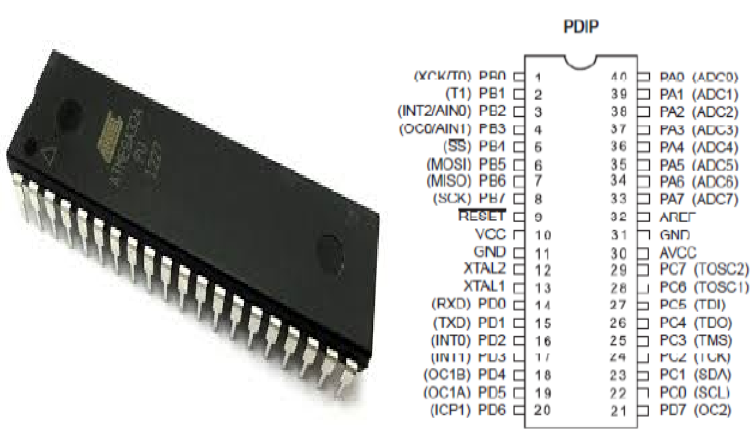


Figure 3.2: A tmega32 microcontroller

- BASCOM AVR programming

The BASCOMAVR program (Figure 3.3) is chose to program Atmga family microcontroller. It writes programs in Basic, translates these programs on the PC to machinecode and simulates the compiled code also enablesthe programmer to use external programs to flash the compiled code into an AtmelAVR microcontroller .

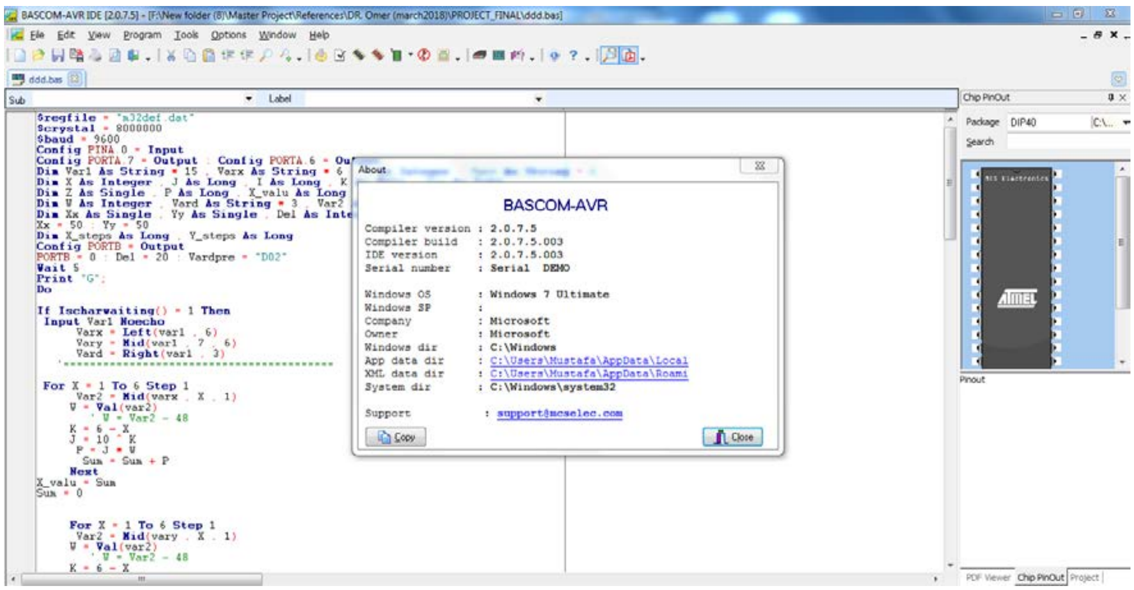


Figure 3.3: BASCOM programming Software

- Proteus Software

Proteus is a virtual system modeling and circuit simulation application as in Figure 3.4. The suite combines mixed mode SPICE circuit simulation, animated components and microprocessor models to facilitate co-simulation of complete microcontroller based designs. Proteus also has the ability to simulate the interaction between software running on a microcontroller and any analog or digital electronics connected to it. It simulates I/P ports, interrupts, timers, USARTs and all other peripherals present on each supported processor.

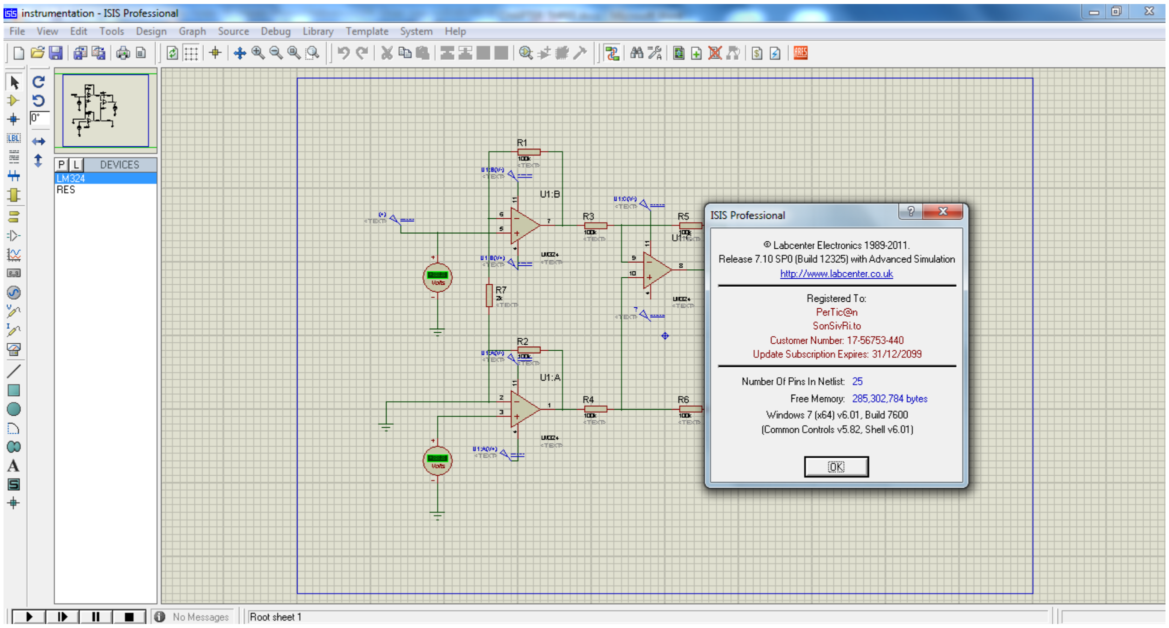


Figure 3.4: Proteus Software

3.3. Electric Motor

An electric motor is an electrical machine that converts electrical energy into mechanical energy. The reverse of this is the conversion of mechanical energy into electrical energy and is done by an electric generator, which has much in common with a motor. Most electric motors operate through the interaction between an electric motor's magnetic field and winding currents to generate force. In certain applications, such as in regenerative braking with traction motors in the transportation industry, electric motors can also be used in reverse as generators to convert mechanical energy into electric power. There are different types of electrical motor according to the operating current: DC motor such as: shunt motor, separately exited motor, series motor, Permanent Magnet DC (PMDC), and Compounded motor; AC motor such as induction motor and synchronous motor. The DC motor can be stepper motor, brushless DC motor, hysteresis motor, reluctance motor, and universal motor. Most of the CNC machines are using either stepper or servo motors, each possessing its own advantages and disadvantages as can be viewed in Table 3.2.

Table (3. 2): Comparison between servo and stepper motor

Characteristics	Servo Motor (DC Brushed)	Stepper
Cost	The cost for a servo motor and servo motor system is higher than that of a stepper motor system with equal power rating.	This feature would have to go to stepper motors. Steppers are generally cheaper than servo motors that have the same power rating.
Reliability	It depends on the environment and how well the motor is protected.	The stepper takes this category only because it does not require an encoder which may fail.
Frame Sizes	Servo motors are available in a wide variety of frame sizes, from small to large motors capable of running huge machines. Many of the motors come in NEMA standard sized.	Stepper motors do not have as many size selections as servo motors in the large sizes. However stepper motors may still be found in a variety of NEMA frame sizes.
Setup Complexity	Servo motors require tuning of the (PID) closed loop variable circuit to obtain correct motor function.	Stepper motors are almost plug-and-play. They require only the motor wires to be wired to the stepper motor driver.
Motor Life	The brushes on servo motors	The bearing on stepper

	must be replaced every 2000 hours of operation. Also encoders may need replacing.	motors are the only wearing parts. That gives stepper motors a slight edge on life.
Low Speed High Torque	Servo motors will do fine with low speed applications given low friction and the correct gear ratio	Stepper motors provide most torque at low speed (RPM).
High Speed High Torque	Servo motors maintain their rated torque to about 90% of their no load RPM.	Stepper motors lose up to 80% of their maximum torque at 90% of their maximum RPM.
Repeatability	Servo motors can have very good repeatability if setup correctly. The encoder quality can also play into repeatability.	Because of the way stepper motors are constructed and operate they have very good repeatability with little or no tuning required.
Overload Safety	Servo motors may malfunction if overloaded mechanically.	Stepper motors are unlikely to be damages by mechanical overload.
Power to Weight/Size Ratio	Servo motors have an excellent power to weight ratio given their efficiency.	Stepper motors are less efficient than servo motors which usually mean a smaller power to weight/size ratio.
Efficiency	Servo motors are very efficient. Yielding 80-90% efficiency given light loads.	Stepper motors consume a lot of power given their output, much of which is converted to heat. Stepper motors are

		usually about 70% efficient but this has some to do with the stepper driver.
Flexibility in Motor Resolution	Since the encoder on a servo motor determines the motor resolution servos have a wide range of resolutions available.	Stepper motors usually have 1.8 or 0.9 degree resolution. However thanks to micro-stepping steppers can obtain higher resolutions. This is up to the driver and not the motor.
Torque to Inertia Ratio	Servo motors are very capable of accelerating loads.	Stepper motors are also capable of accelerating loads but not as well as servo motors. Stepper motors may stall and skip steps if the motor is not powerful enough.
Least Heat production	Since the current draw of a servo motor is proportional to the load applied, heat production is very low.	Stepper motors draw excess current regardless of load. The excess power is dissipated as heat.
Reserve Power and Torque	A servo motor can supply about 200% of the continuous power for short periods.	Stepper motors do not have reserve power. However stepper motors can brake very well.
Noise	Servo motors produce very little noise.	Stepper motors produce a slight hum due to the control process. However a high

		quality driver will decrease the noise level.
Resonance and Vibration	Servo motors do not vibrate or have resonance issues.	Stepper motors vibrate slightly and have some resonance issues because of how the stepper motor operates.
Availability	Servo motors are not as readily available to the masses as are stepper motors.	Stepper motors are far easier to find than quality servo motors.
Motor Simplicity	Servo motors are more mechanically complex due to their internal parts and the external encoders.	Stepper motors are very simple in design with no designed consumable parts.
Direct Drive Capability	Servo motors usually require more gearing ratios due to their high RPM. It is very rare to see a direct drive servo motor setup.	Stepper motors will work fine in direct drive mode. Many people simple use a motor couple and attach the motor shaft directly to the leadscrew or ballscrew.
Power Range	Because servo motors are available in DC and AC servo motors have a very wide power availability range.	The power availability range for stepper motors is not that of servo motors. [**18**]

Depending on the above comparison and according to the proposed system requirements and specifications such as cost, positional accuracy requirement, torque requirement, drive power availability and acceleration requirement, stepper motors are more suitable.

- Stepper motor

A stepper motor (Figure 3.5) 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 shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied .One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. The position is known simply by keeping track of the input step pulses [17]. The stepper motor can only take one-step at a time and each step has the same size. Since each pulse causes the motor to rotate an accurate angle, typically 1.8 degree, the motor's position can be controlled without any feedback mechanism. As the digital pulses increase in frequency, the step movement changes into continuous rotation, with the speed of rotation directly proportional to the frequency of the pulses.

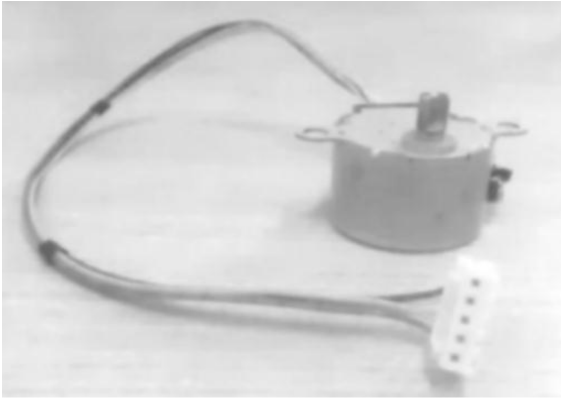


Figure 3.5: Stepper motor with connection

There are two types of stepper motor as follow as

i. Unipolar stepper motor

The unipolar stepper motor has five or six wires and four coils as in figure 3.6 (actually two coils divided by centre connections on each coil). The centre connections of the coils are tied together and used as the power connection.They are called unipolar steppers because power always comes on this one pole.

ii. Bi-polar Stepper Motor:

The bipolar stepper motor usually has four wires as shows in figure 3.6 coming out of it. Unlike unipolar steppers, bipolar steppers have no common centre connection. They have two independent sets of coils instead.

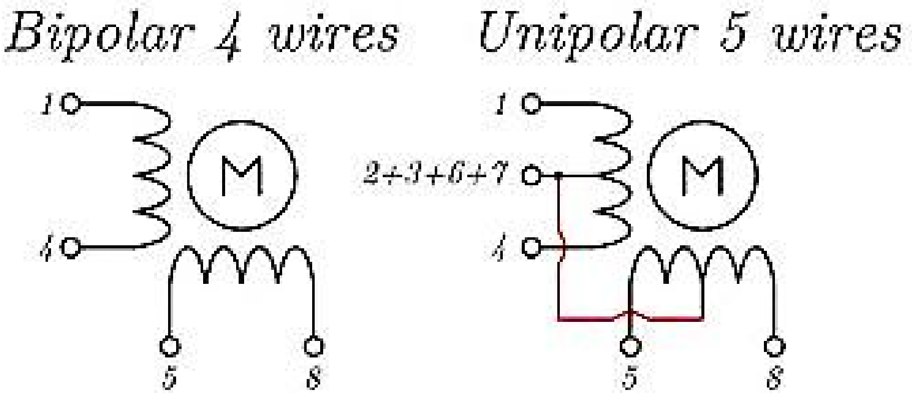


Figure 3.6: Bipolar and Unipolar stepper motor wiring

The advantages of stepper motor can be as follow:

1. The rotation angle of the motor is proportional to the input pulse.
2. The motor has full torque at standstill (if the windings are energized)
3. Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3–5% of a step and this error is non-cumulative from one step to the next.
4. Excellent response to starting/stopping/reversing.
5. Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.
6. The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.
7. It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
8. A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

The disadvantages of stepper motor can be:

1. Resonances can occur if not properly controlled.
2. Not easy to operate at extremely high speeds.

The driver (or amplifier) converts the indexer command signals into the power necessary to energize the motor windings. There are numerous types of drivers, with different voltages and current ratings and construction technology. Not all drivers are suitable to run all motors, so when designing a motion control system the driver selection process is critical. An analogue circuit allows for control of one stepper motor. The circuit is essentially the stepper motor driver. The circuitry based around the l297 and l298 shown in Figure 3.7 stepper driver combo. The l297 takes the signal from the microcontroller and translate them into stepping signals to send to the l298. The l298 is the actual driver of the stepper motor. The l298 provides capacity of 2A of current per coil. The l297 is also great for ability to sense the amount of current flowing through the coil and will chop the signal to the l298 chip so that the average current flow is more desirable. This allows custom current to fix the motor. The connection between these two chips can be shown in Figure 3.8.

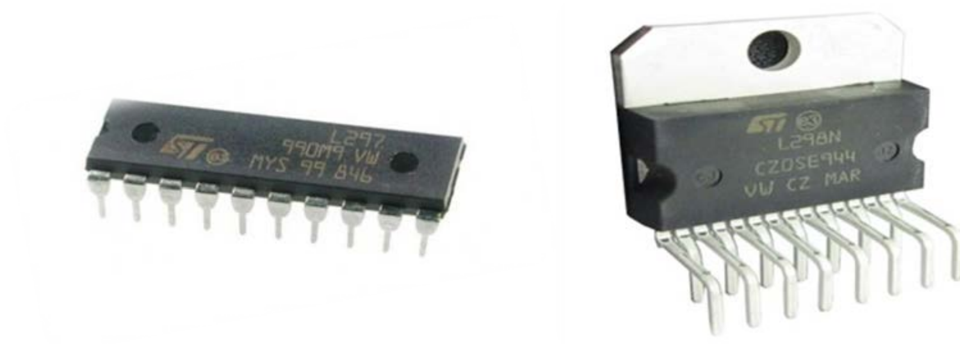


Figure 3.7: L297 and L298 drivers integrated circuit

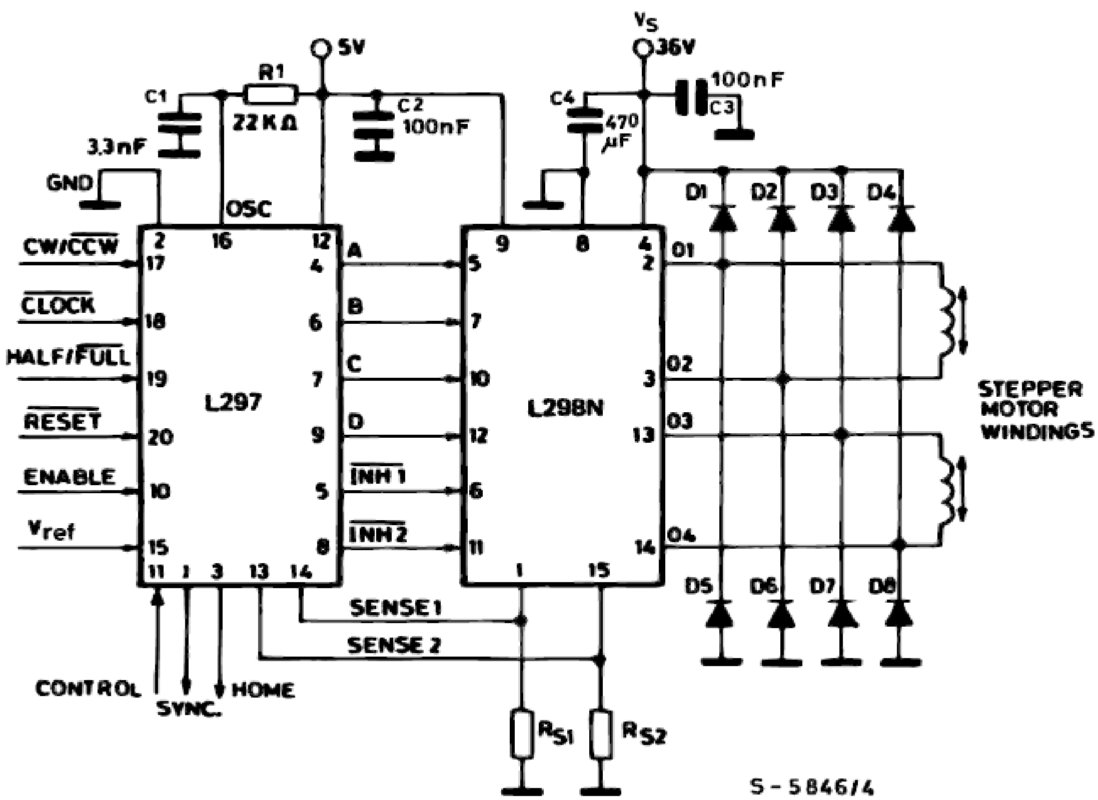


Figure 3.8: L297 and L298 schematic circuit

For the purpose of this research, the VRDM stepper motor is selected (Figure 3.9) .VRDM 397 = 3-phase stepping motor of size 90 (i.e. the length of the connecting flange isapproximately 90 mm) and of length 70 (i.e. the length of the motor [stator package and flanges] isapproximately 70 mm). Table 3.3 shows the classification of VDRM stepper motor.

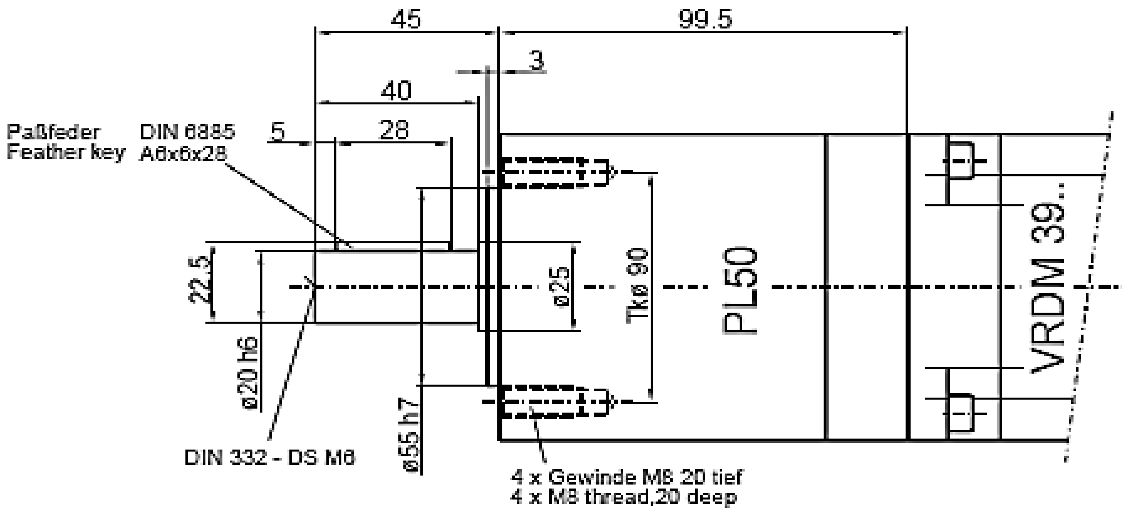


Figure 3.9: VDRM motor

Table 3.3: Classification of VDRM stepper motor

Motor type				VRDM 397	VRDM 3910	VRDM 3913
Max. torque	M_m	Nm	LN 5) / LW 7)	2	4	6
			LH 6)	1,7	3,7	-
Holding torque	M_H	Nm	LN 5) / LW 7)	2,26	4,52	6,78
			LH 6)	1,92	4,18	-
Rotor inertia	J_R	kgcm²		1,1	2,2	3,3
Number of steps 1)	z			200 / 400 / 500 / 1000 / 2000 / 4000 / 5000 / 10000		
Step angle 1)	α	°		1,8 / 0,9 / 0,72 / 0,36 / 0,18 / 0,09 / 0,072 / 0,036		
Systematic angle tolerance per step 2)	$\Delta\alpha_s$	'		±6		
Max. starting frequency 1)	f_{Aom} 4)	kHz	LN 5) / LW 7)	5,3		
			LH 6)	5	4,8	-
Rated current of incoming cable	I_W	A	LN 5)	4,4	5,0	5,0
			LH 6)	5,5	5,5	-
			LW 7)	1,75	2,0	2,25
Winding resistance	R_W	Ω	LN 5)	1,0	1,2	1,3
			LH 6)	0,35	0,55	-
			LW 7)	6,5	5,8	6,5
Current rise constant	τ	ms		~ 7	~ 9	~ 10
Shaft load				See page 4		
Motor voltage	U	V	LN 5)	130		
			LH 6)	40		
			LW 7)	325		
Approximate weight 3)	m	kg		1,65 / 2,05	2,7 / 3,1	3,8 / 4,2

To determine the horizontal movement distances for the chosen stepper motor the following calculation can be followed:

- Motor shaft circumference =D* π= 0.25 * π= 0.7853 mm (where D is the shaft diameter)
- Number of stepsfor Compete turn= 360º/25.6º= 14.0625 steps.
- Therefore, the number of required steps for desired distance=$\frac{\text{desired distance}*14.0625}{0.7853}\,mm$.

3.4 Implementation of the Microcontroller and Motors with their Drivers

The proposed microcontroller and associated motors with their driver can be implemented as in Figure 3.10 using Proteus ISIS platform. The interaction between the connected motors and the governed microcontroller can be viewed from the flowchart in Figure 3.11.

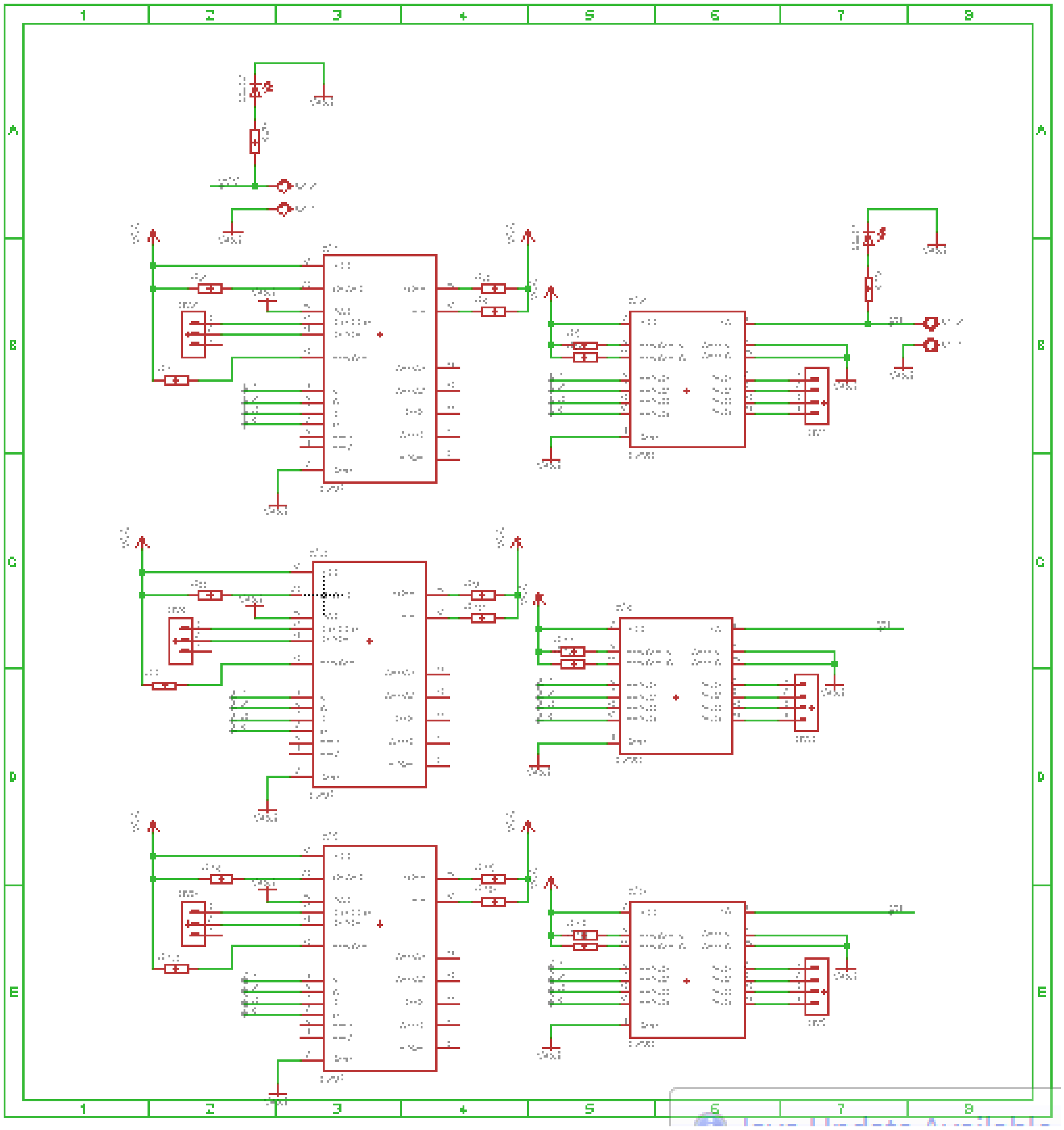


Figure 3.10: Schematic circuit diagram for motors and its drivers`

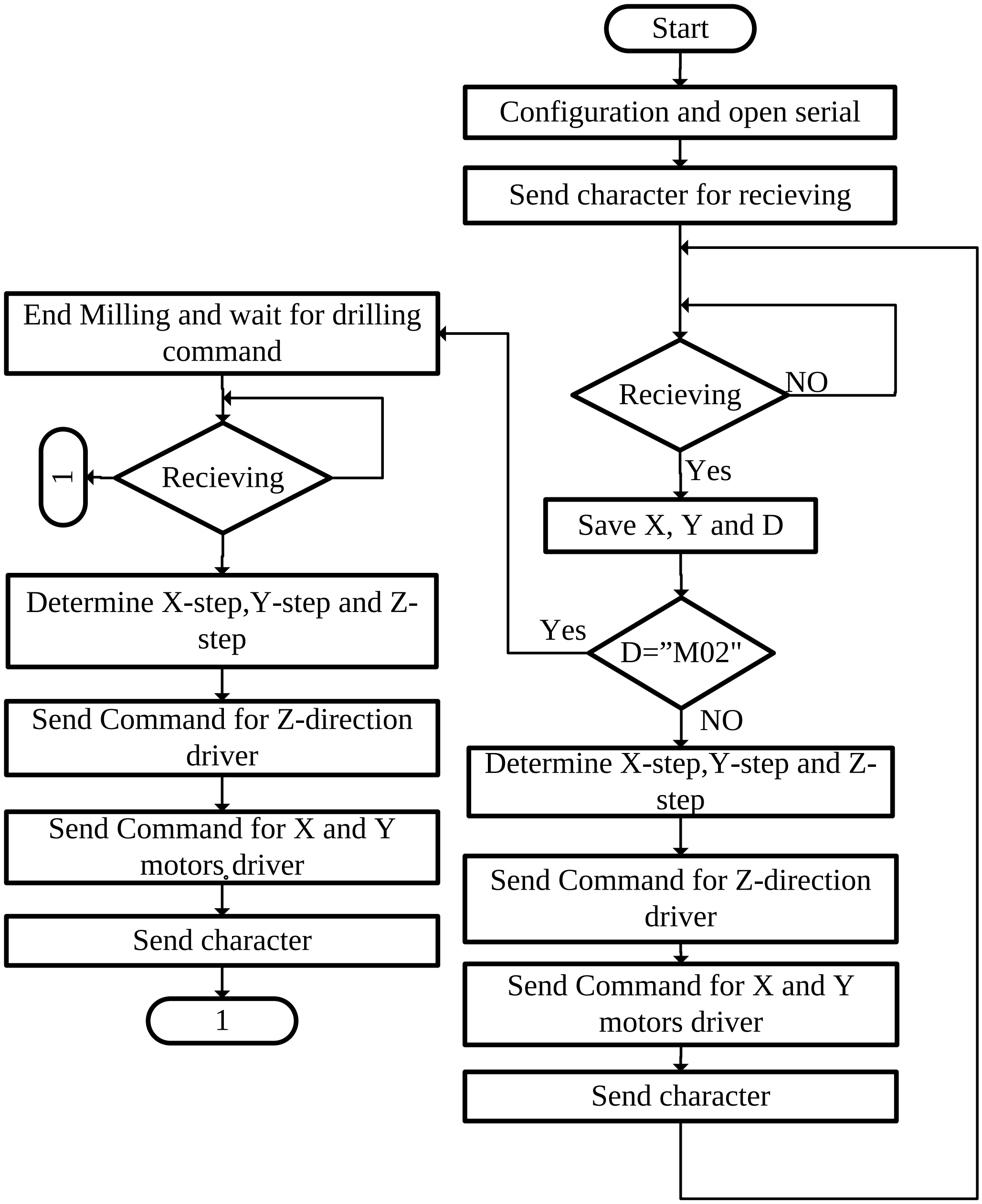


Figure 3.11: Flowchart of microcontroller code

Microcontroller send character to MATLAB for receiving first information message in text format and will convert it to integer format, and separate it to three parts: part one consists first six characters for x-coordinate, second part consists six characters for y-coordinate and last part consists three characters for z motion information as in Figure 3.12. The moving motor distance and its direction can be determined by x and y coordinates, where the distance was calculated previously. Figure 3.13 and figure 3.14 shows the screen shoot of BASCOM code for motors and PCB artwork for three stepper motors respectively.

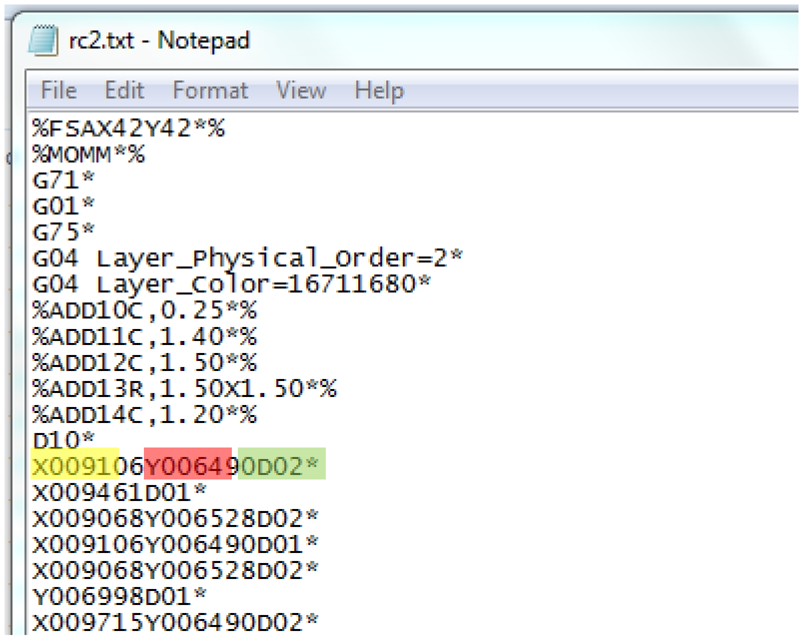


Figure 3.12: Screenshot of Gerber file with the X, Y and Z coordinates digits representation

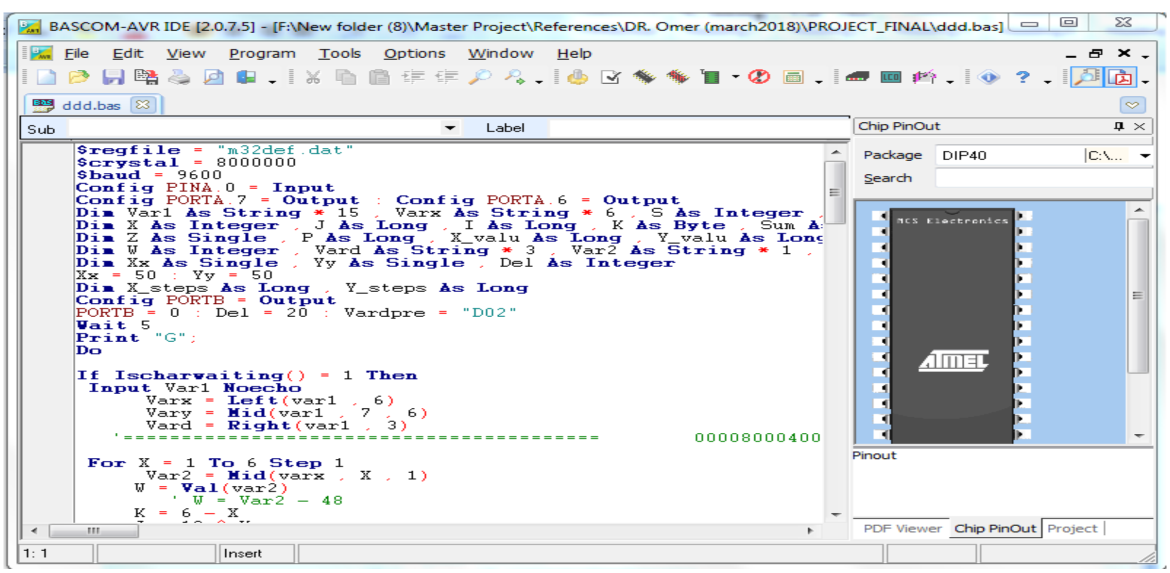


Figure 3.13: Screenshot of BASCOM code for motors

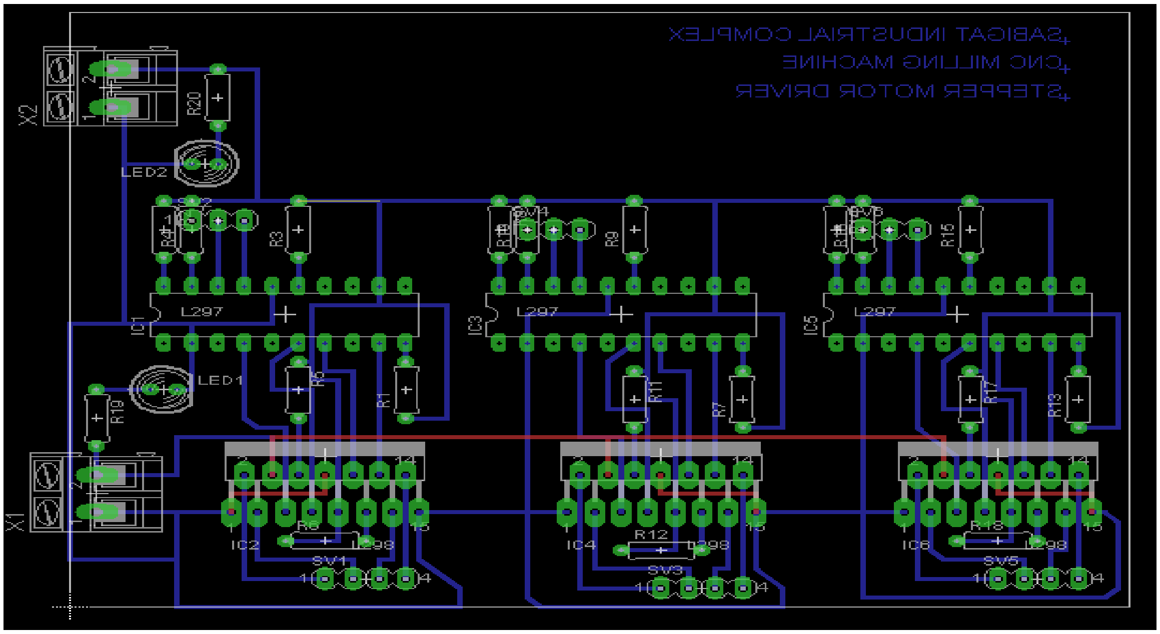


Figure 3.14: PCB artwork for the three stepper motors

3.5 Communication Unit

The serial port is a type of connection of PCs that is used for peripherals such as mice, gaming controllers, modems, and older printers. It is sometimes called a COMmunication (COM) port or an RS-232 port, which is its technical name. There are two types of serial ports DB9 and DB25. DB9 (Figure 3.15) is a 9-pin connection, and DB25 is 25-pin connection. A serial port can only transmit one bit of data at a time, whereas a parallel port can transmit many bits at once.

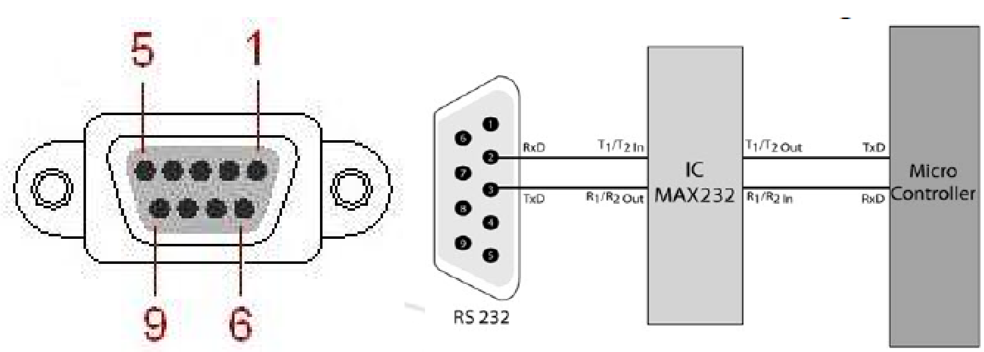


Figure (3.15) Female DB-9(RS-232) serial port

RS232 is a serial interface means that data is transferred Bit by Bit at a time. Since data is transferred Bit by Bit so, itonly need a single wire to send data and another one to receive data. One more common wire (called ground GND) is required between two separate circuits to enable current flow. So a total of three wires are required for communication. RS232 can be used to communicate between varieties of devices. Like the MCU, Global Position System (GPS) receiver and a Global System for Mobile (GSM) module or a PC. A connection between an ATMEGA16/32 MCU and a standard PC can be demonstrated in the following: On the PC, a terminal program like real thermo-hyper terminal can be run. A terminal program is used to send and receive text data. So any text send by the MCU will be visible on terminal screen and any key press you make on the PC keyboard will be send over RS232 to your MCU. This configuration is the simplest setup to test and understand RS232 communication. When you have enough knowledge you can replace the terminal with your own PC end software for sending and receiving data. It's time to put that funny looking port on the back of your PC to some good use! If you don't have a serial port on your PC, you can get a USB to serial converter/adapter. At one time, there was a wide range of devices that used the serial port such as a mouse, keyboard, old GPS, modems and other networking.

The RS-232 acts as a connector for the microcontroller to communicate to transmit and receive data. Pins 11 and 12 of the MAX232 chip are connected to pins 10(RxD) and 11(TxD) of the microcontroller respectively. Pins 13 and 14 are connected to pins 2 and 3 of the DB-9 pin connectors. Input voltages of +5V and -5V are needed for the operation of this Integrated Circuit (IC) chip. Pin 2 is to receive data and pin 3 is to transmit data. Pin 5 of the DB-9 connectors is shorted to ground. The Max232 serves as a driver for the transmitting and receiving of data [15].The male DB-9 connector and gives output to the PC and the female connector gives output to the modem. Table 3.4 illustrates RS-232 DB-9 connector a pin out and functions.

Table 3.4: RS-232 DB-9 Connector Pin out and functions

Pin #	Acronym	Full Name	Meaning
3	TxD	Transmit Data	Transmits bytes out of system
2	RxD	Receive Data	Receives bytes into system
7	RTS	Request to send	RTS/CTS Flow Control
8	CTS	Clear to send	RTS/CTS Flow Control
6	DSR	Data Set Ready	Ready to Communicate
4	DTR	Data Terminal Ready	Ready to Communicate
1	DCD	Data Carrier Detect	Modem Connected to another.Data Carrier detect (This line is active when modem detects a carrier
9	RI	Ring Indicator	Ring Indicator (Becomes active when modem detects ringing signal from PSTN
5	GND	Signal Ground	Grounding

The MAX-232 IC (Figure 3.16) is an integrated circuit which consists of 16 pins and it is a resourceful IC mostly used in the voltage level signal problems. Generally, the MAX-232 IC is used in the RS232 communication system for the conversion of voltage levels on TTL devices that are interfaced with the PC serial port and the microcontroller. This IC is used as a hardware layer converter like to communicate two systems simultaneously.

Figure 3.16: MAX232 IC and interface

Further the MAX232 IC is extended by the four receivers and transmitters simultaneously with eight receivers and transmitters which are MAX238 and MAX248 and there are many combinations of receivers and transmitters [18].

3.6 MATLABPlatform

The name ‘MATLAB’ comes from two words: MATrix and LABoratory . According to the MathWorks (producer of MATLAB), MATLAB is a technical computing language used mostly for high-performance numeric calculations and visualization. It integrates computing, programming, signal processing and graphics in easy to use environment, in which problems and solutions can be expressed with mathematical notation. Basic data element is an array, which allows for computing difficult mathematical formulas, which can be found mostly in linear algebra. But MATLAB is not only about math problems. It can be widely used to analyze data, modeling, simulation and statistics. MATLAB high-level programming language finds implementation in other fields of science like biology, chemistry, economics, medicine and many more [19]. Figure 3.18 shows the screenshot of MATLAB software.

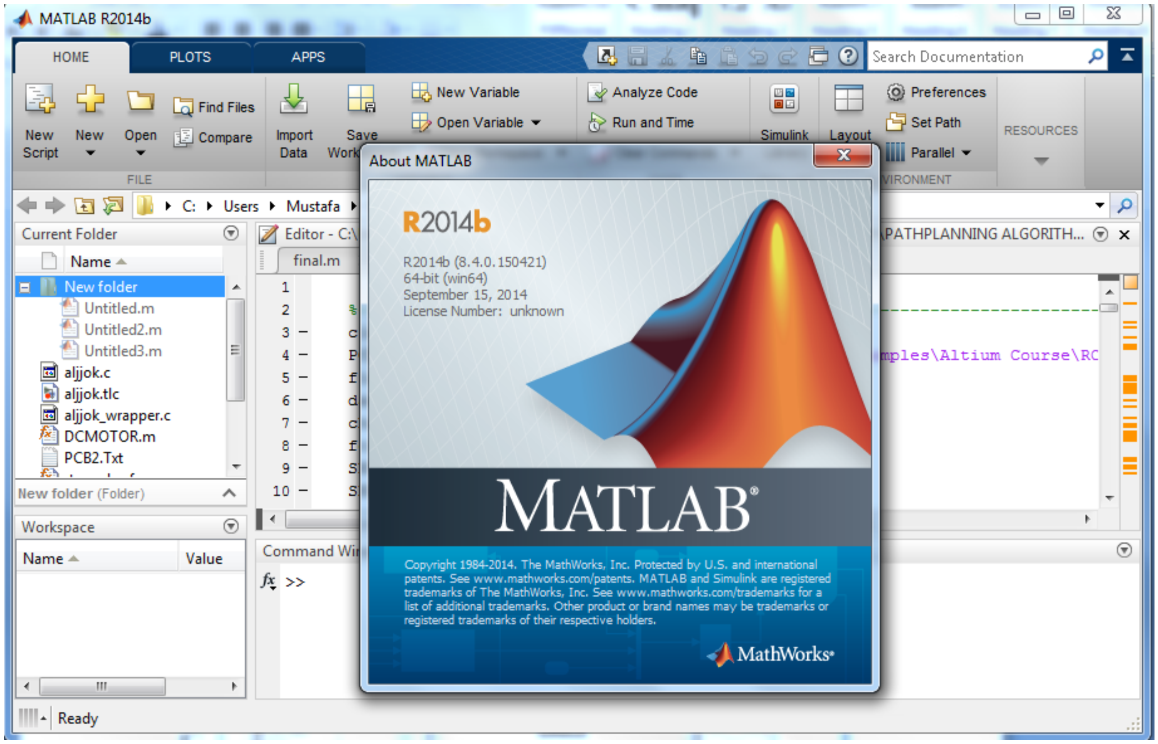


Figure 3.17: Screenshot of MATLAB software environment

3.7 EAGLE Software

Easily Applicable Graphical Layout Editor (Eagle) is PCB design software to design an electronic schematic and layout a PCB. Eagle (Figure 3.18) is consisting of a schematics editor, a PCB editor and an auto-router module. The software comes with an extensive library of components, but a library editor is also available to design new parts or modify existing ones. Eagle is made by CadSoft (http://cadsoft.de), and is available in three versions. The light version is limited to one sheet of schematics and half euro-card format (80×100 mm), but can be used under the terms of the freeware license for non-commercial use. This software can be downloaded from CadSoft's homepage, for Windows or Linux .

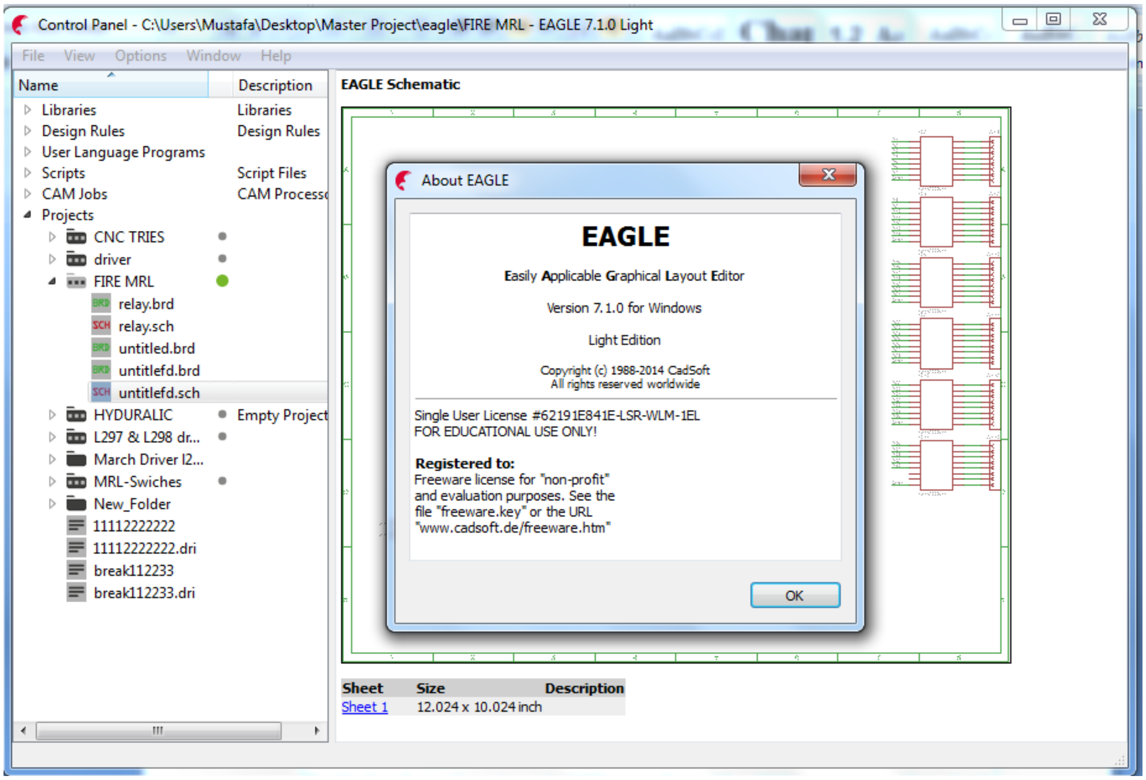


Figure 3.18: Screenshot EAGLE software

3.8 Gerber File

The Gerber format is an open ASCII vector format for 2D binary images. It is the deface to standard used by PCB industry software to describe the printed circuit board images: copper layers, solder mask, and legend. Gerber is used in PCB fabrication data. PCBs are designed on a specialized Electronic Design Automation (EDA) or a computer-aided design (CAD) system. The CAD systems output PCB fabrication data to allow fabrication of the board. This data typically contains a Gerber file for each image layer (such as copper layers, solder mask, and legend or silk). Gerber is also the standard image input format for all bare board fabrication equipment needing image data, such as photo, legend printers, direct imagers or Automated Optical Inspection (AOI) machines and for viewing reference images in different departments. For assembly the fabrication data contains the solder paste layers and the central locations of components to create the stencil and place and bond the components. Table 3.5 illustrated the Gerber file.

Table 3.5: Gerber command overview

Command	Description
FS	Format statement. Sets the coordinate format, e.g. the number of decimals.
MO	Mode. Sets the unit to inch or mm.
AD	Aperture defines. Defines an aperture and assigns a D code to it.
AM	Aperture macro. Defines a macro aperture template.
AB	Aperture block. Defines a block aperture and assigns a D-code to it.
Dnn (nn≥10)	Sets the current aperture to D code nn.
D01	Interpolate operation. Outside a region statement D01 creates a draw or arc object using the current aperture. Inside it creates a linear or circular contour segment. After the D01 command the current point is moved to draw/arc end point.
D02	Move operation. D02 does not create a graphics object but moves the current point to the coordinate in the D02 command.
D03	Flash operation. Creates a flash object with the current aperture. After the D03 command the current point is moved to the flash point.
G01	Sets the interpolation mode to linear.
G02	Sets the interpolation mode to clockwise circular.
G03	Sets the interpolation mode to counterclockwise circular.
G74	Sets quadrant mode to single quadrant.

G75	Sets quadrant mode to multi quadrant.
LP	Load polarity. Loads the polarity object transformation parameter.
LM	Load mirror. Loads the mirror object transformation parameter.
LR	Load rotation. Loads the rotation object transformation parameter.
LS	Load scale. Loads the scale object transformation parameter.
G36	Start region statement. This creates a region by defining its contour.
G37	Ends region statement.
SR	Step and repeat. Open or closes a step and repeat statement.
G04	Comment.
TF	Attribute file. Set a file attribute.
TA	Attribute aperture. Add an aperture attribute to the dictionary or modify it.
TO	Attribute object. Add an object attribute to the dictionary or modify it.
TD	Attribute delete. Delete one or all attributes in the dictionary.
M02	End of file.

3.9 Virtual Serial Port (VSR)

Virtual serial port driver is (Figure 3.19) an advanced utility, which creates virtual serial ports and connects them into pairs via virtual null-modem cable. Applications on both ends of the pair can exchange data in such a way, that written to one virtual serial port, it can be immediately read from the other one, and vice versa. Virtual serial ports appear to an operating system or any Windows application as "standard" hardware serial ports, supporting all serial port settings, strict baud rate emulation, hand-flow control and signal lines. Once virtual ports pair is created, virtual serial ports appear in device manager, moreover, they are available at each system startup, even prior to user login.Virtual serial port driver can be included into your own software (OEM License), thus providing simple way to create and configure virtual serial ports directly from your application.

Figure 3.19: Screen-shot of virtual serial port

3.10 Implementation and Interconnection for analysis Gerber by MATLAB and the communication between MALAB and Microcontroller

Figure 3.20 shows the flow chart of G-to-C-code. In order to make the G-code interface with the microcontroller, each part of the G-code line will be treated as a separate character, where a suitable C-code to present the G-code will be written, after that several functions made by C-code will be executed.

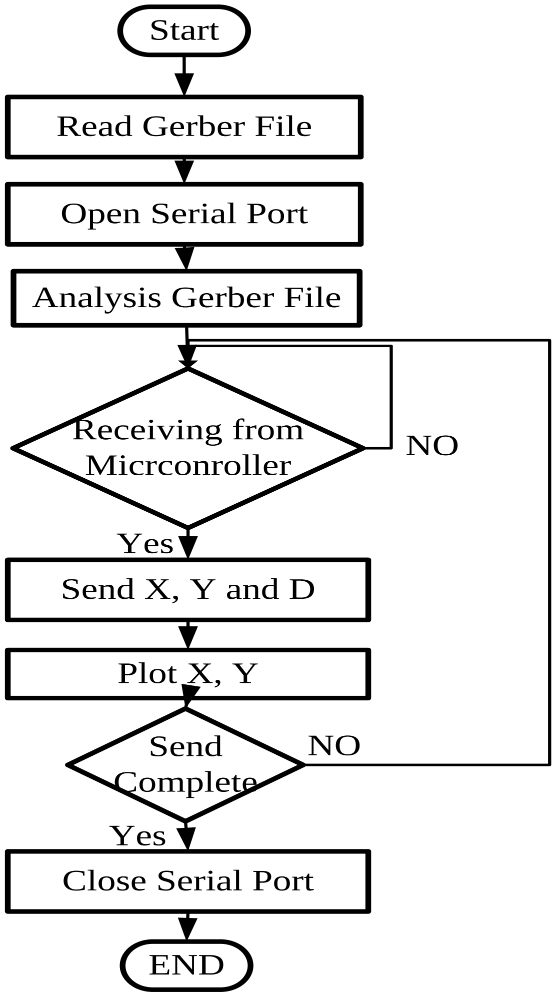


Figure 3.20: Flowchart of analysis Gerber files and send it to microcontroller

Gerber file was exported from text file in MATAB and analyzed to determine the three axes x, y and z coordinates in each row and type of motion (milling or moving) which is considered as one information message (Figure 3.22). Type of motion is explained by: “D01” indicates up position of spindle, “D02” indicates down position of spindle and “D03” indicates drill operation. X, Y and Z coordinate is determined in (mm).

The information message length is 16 characters separated to three parts: first part consists of six characters for X-coordinate, second part consists of six characters for Y-coordinate and last part consists of three characters for Z. To send this information message, MATLAB shall wait for receiving character from the microcontroller to ensure that it is ready for get next message after complete its mission. Communication is done by serial communication. Figure 3.21 shows schematic circuit diagram for Microcontroller with serial port.

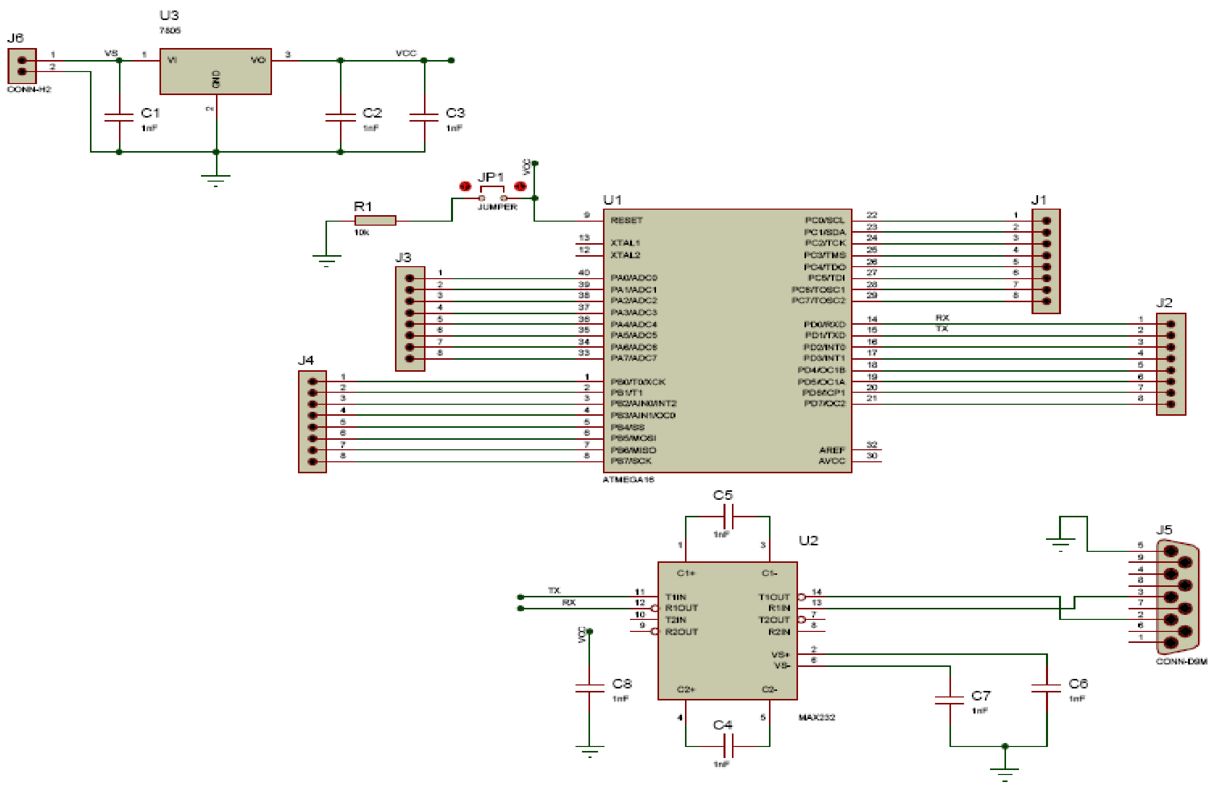


Figure 3.21: Schematic circuit diagram for microcontroller with serial port

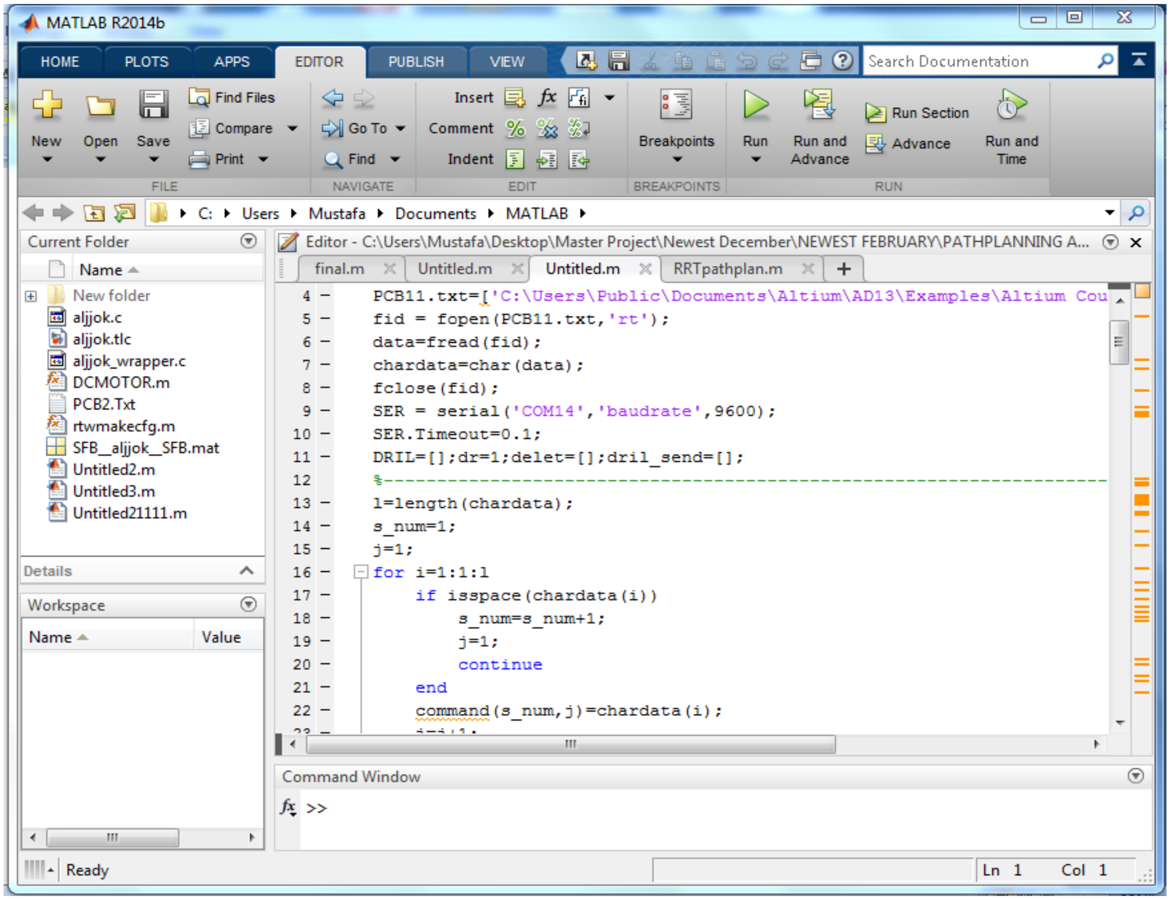


Figure 3.22: The MATLAB code of Gerber-to-C code

3.11 Implementation and Interconnection of Path Planning Technique for Drilling Process

Figure 3.23 and Figure 3.24 show the flowchart and implementation of the sorted coordinate's path planning for drilling process and screenshot of MATLAB for path planning algorithm respectively. All drilling coordinates reordered in matrix (x_n,y_n) path planning algorithm is combination of row-by-row technique and near neighbor technique. For row-by-row technique minimum y-coordinate will be saved and it's all common points. Common points will be visited to be drilled ascending or descending instate of x-coordinate. Next points will be selected by using near neighbor technique by determine next minimum y-coordinate. Then all common points will be visited by using same technique.

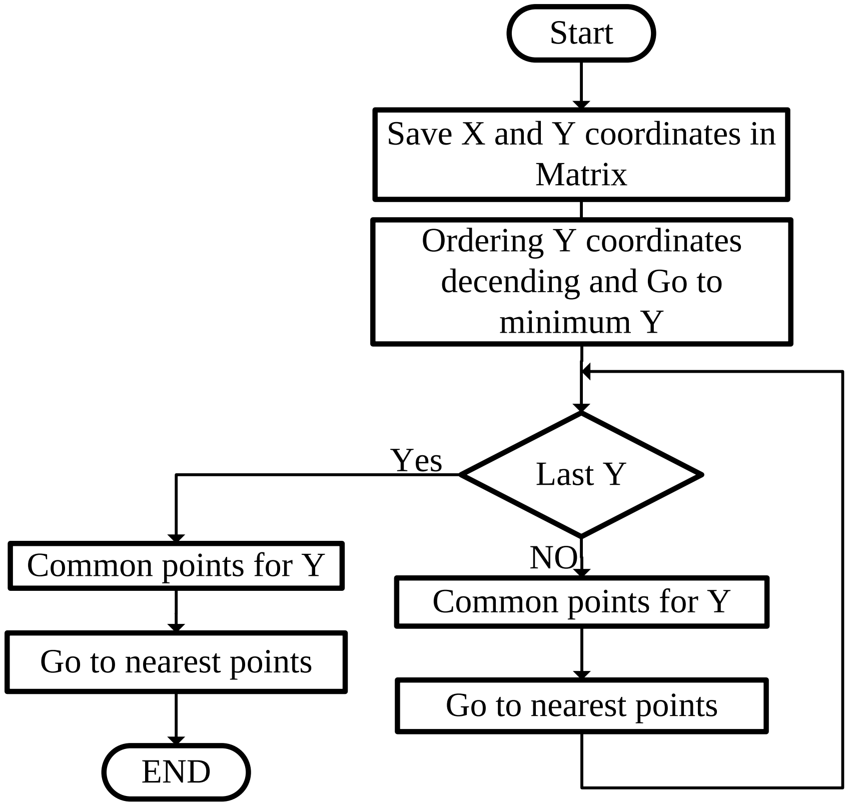


Figure 3.23: Flowchart of sorted coordinate's path planning for drilling process

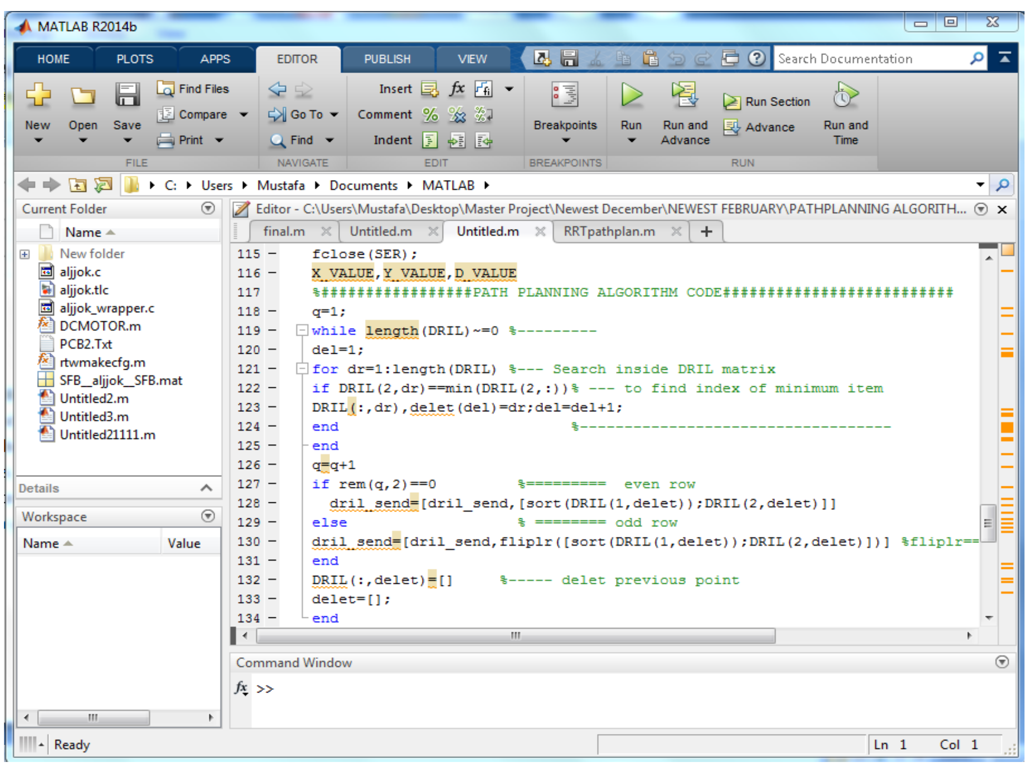


Figure 3.24: Screenshot of MATLAB code for path planning algorithm

CHAPTER FOUR

RESULTS AND DISCUSSION

CHAPTER FOUR

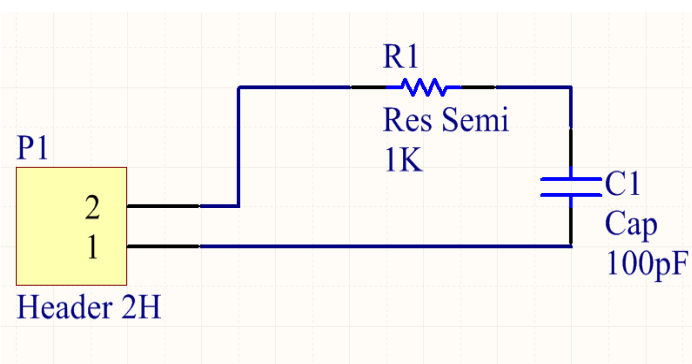
RESULTS AND DISCUSSION

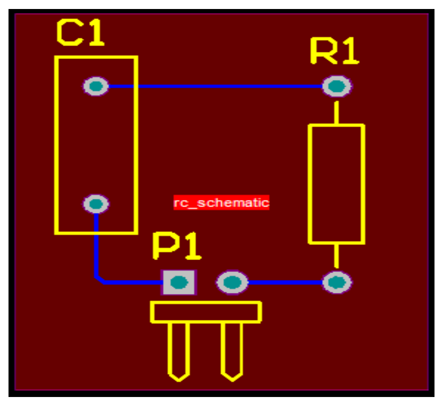
4.1 Introduction

In this chapter the designed PCB CNC machine is tested. The test is achieved by drawing a simple RC circuit to generate the Gerber file. Then this file is analyzed by the MATLAB m-file and sent to the machine through the serial communication. In addition, the implementation of the sorted coordinate's algorithm for path planning is also tested.

4.2 RC Circuit Gerber file Generation

The PCB designer software was used to draw simple RC circuit with header connection (schematic and PCB) as in Figure 4.1. Then generated Gerber can be shown in Figure 4.2.





(a) Schematic diagram (b) PCB artwork

Figure 4.1: RC circuit

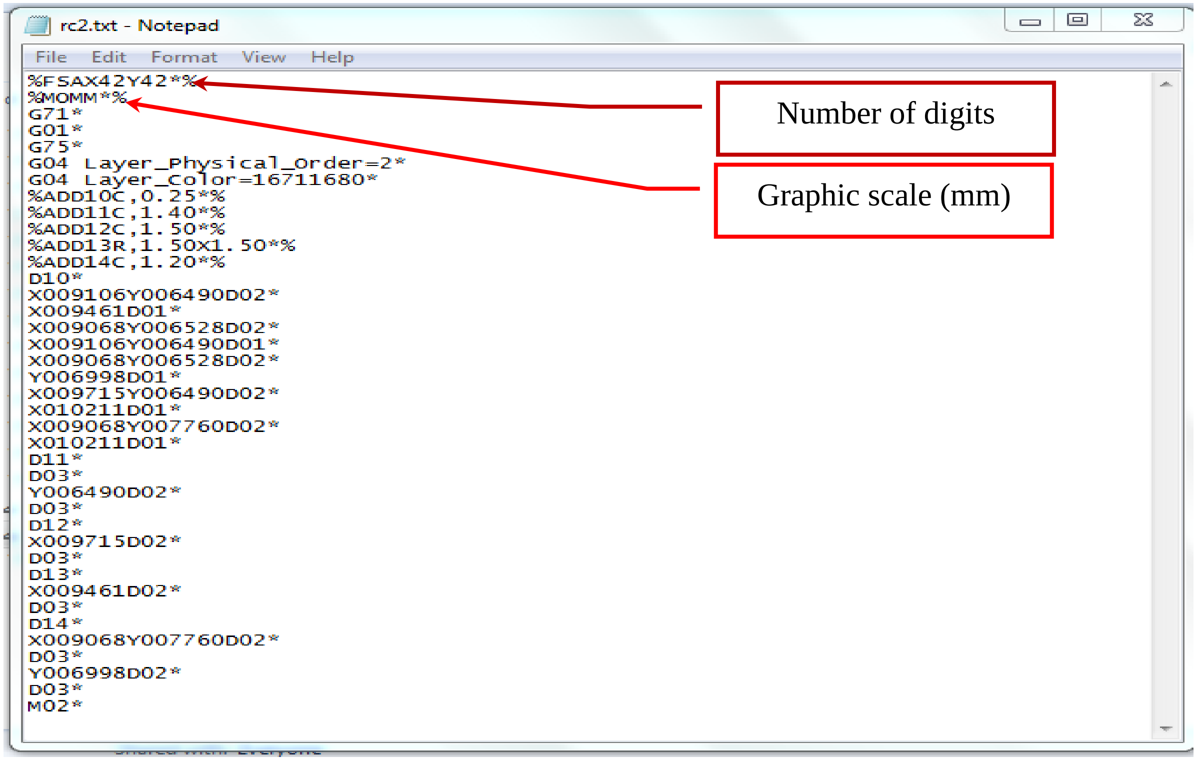


Figure 4.2 Gerber file generated by PCP designer software

4.3 The G-Code to C-Code using MATLAB m-file

The developed MATLAB software was used to open the generated Gerber file (i.e. G-Code) to be analyzed and converted to C-code. Some common configuration was set for PCB designer Software and MATLAB software such as graphic scale which set in (mm) and number of digits which was four digits for integer and two digits for decimal. However, the opened Gerber file in MATLAB was shown in Figure 4.3.

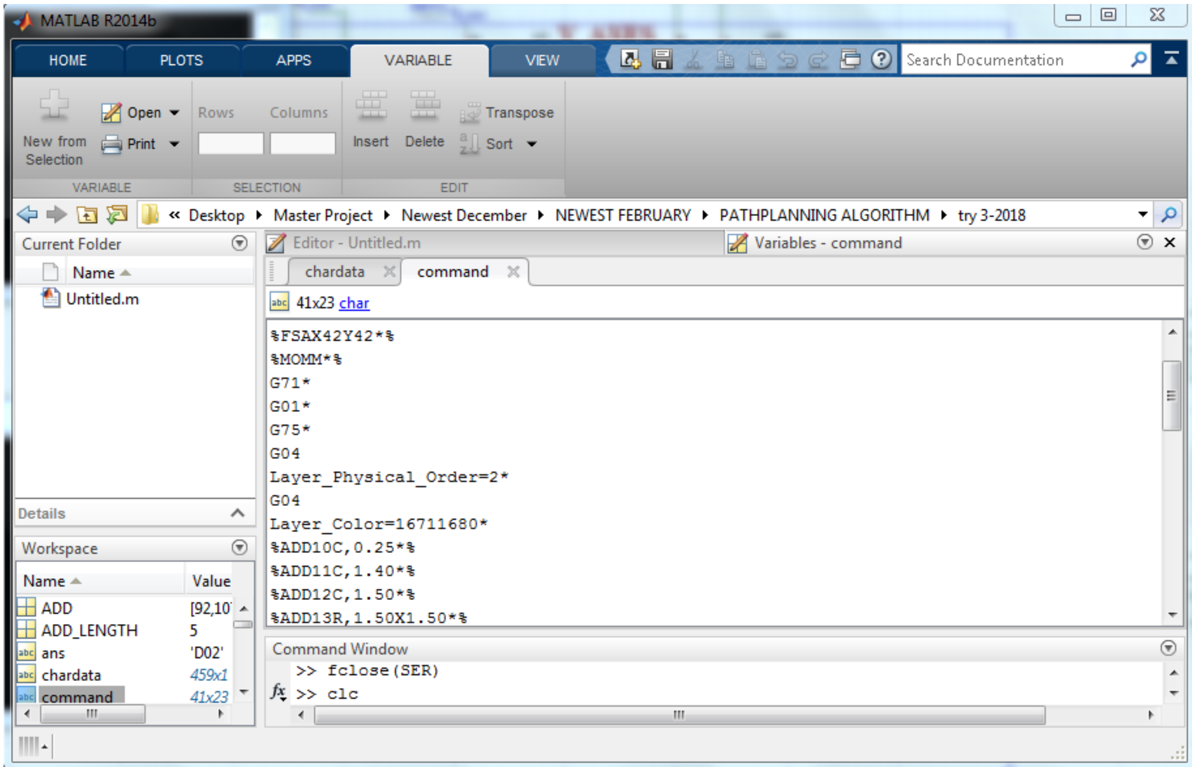


Figure 4.3: The RC circuit Gerber file in MATLAB platform

In addition, the Virtual Serial Port was enabled to provide the communication between Proteus ISIS software and MATLAB platform through the serial communication RS232 COM2 and COM1 for Proteus and MATLAB respectively as in Figure (4.4) with 9600Bps as a baud rate. Figure 4.5 shows the execution of both Proteus ISIS and MATLAB to simulate the operation of PCB CNC machine in Proteus ISIS responding to generated C-code by the MATLAB platform. To start receiving the converted C-code from the MATLAB platform, the PCB CNC machine microcontroller sends “G” character through the serial port to the developed MATLAB script file requesting the first information message. In Figure 4.6, the first information message was sent by MATLAB and received by the PCB CNC machine Microcontroller in Proteus ISIS (i.e. Virtual Terminal). The complete information message for the milling points of RC circuit Gerber file can be shown in Figure 4.7.

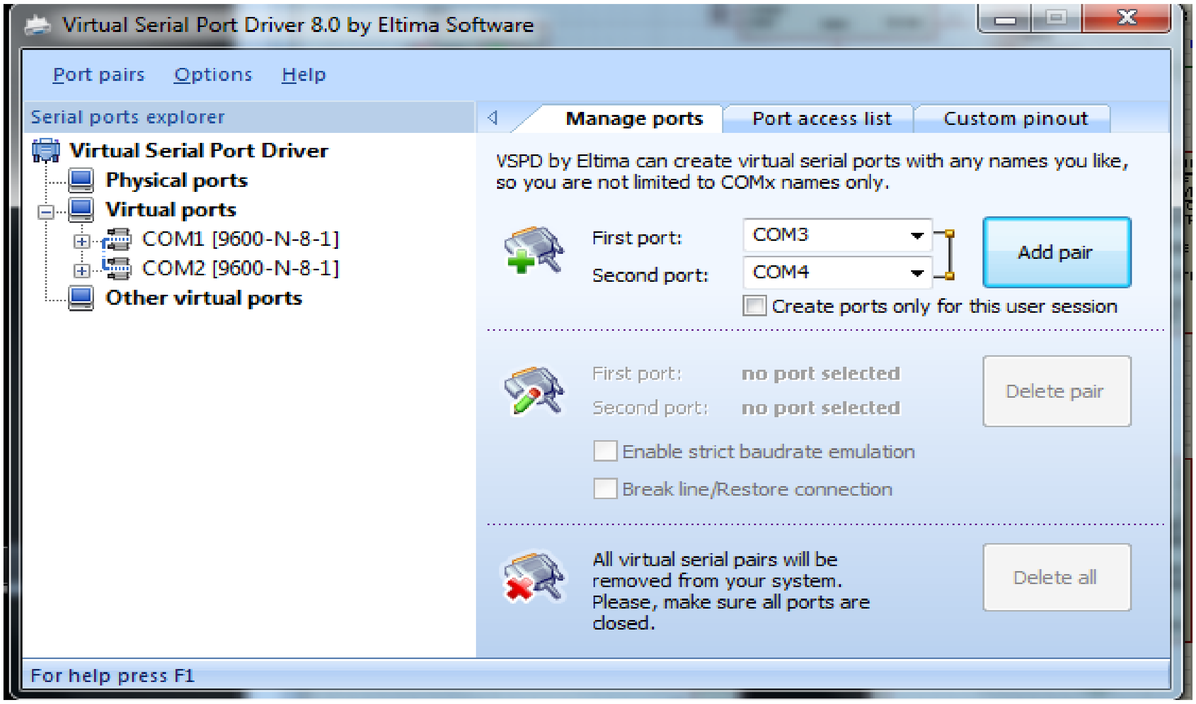


Figure 4.4: Virtual serial port enabling and configuration

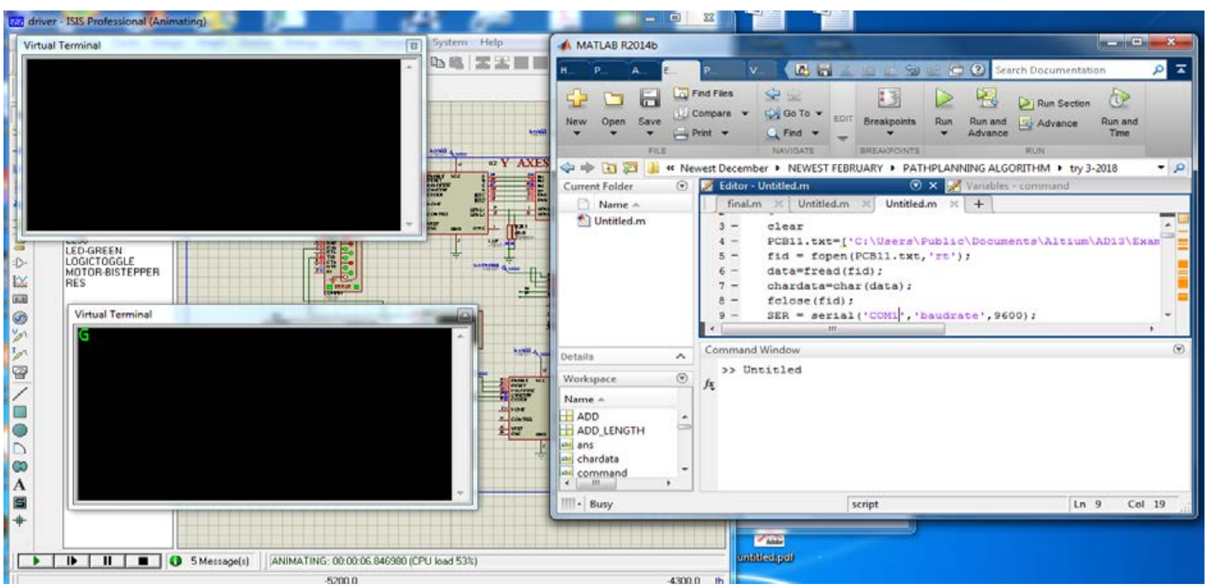


Figure 4.5: Execution of the complete proposed PCB CNC machine in both Proteus ISIS and MATLAB platforms

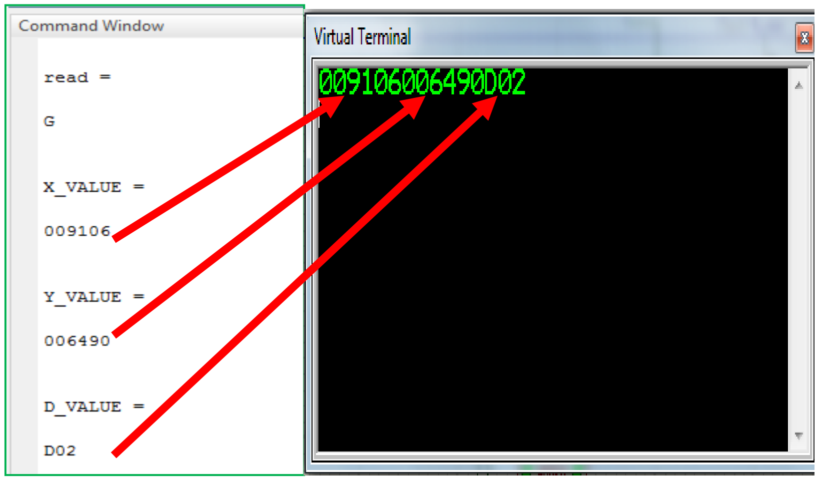


Figure 4.6:the First information message of milling point from MATLAB (PC) to PCB CNC machine Microcontroller for the RC circuit Gerber file

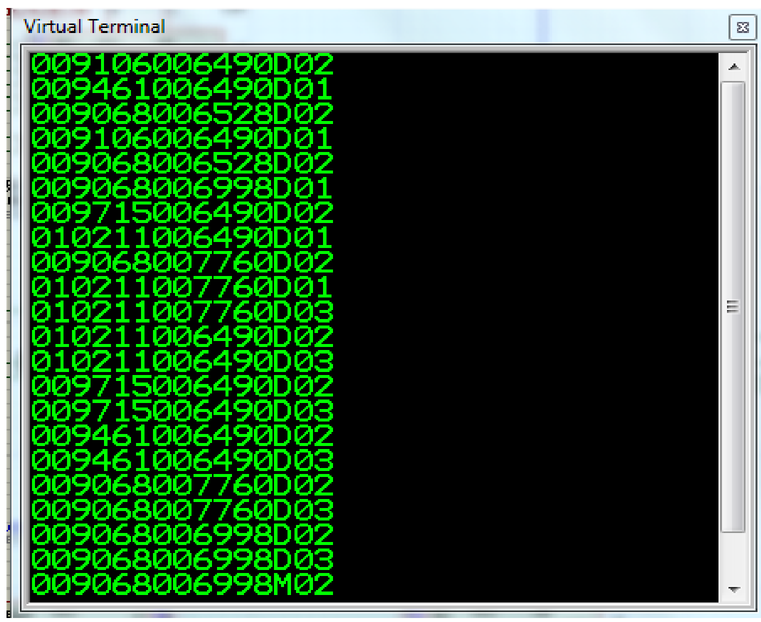


Figure 4.7: The complete information messages of milling points from MATLAB (PC) to PCB CNC machine Microcontroller for the RC circuit Gerber file

After receiving this requested information message, the PCB CNC machine microcontroller processed it to move the associated motors through their drivers accordingly. After the associated motors have completed their movement, the PCB CNC machine microcontroller send “g” character to receive the next information message. This operation is repeated until the completion of milling points in the Gerber file as in Figure 4.8.Moreover, completion of the milling points is indicated by “M02” in Gerber file, therefore, an indicator lamp is turn ON to indicate the completion of PCB tracks printing and wait for the next drilling process which can be started by pressing the Drilling Button. Figure 4.9 shows the generated PCB tracks of RC circuit by the PCB designer Software and the developed m-file in MATLAB platform using milling points.

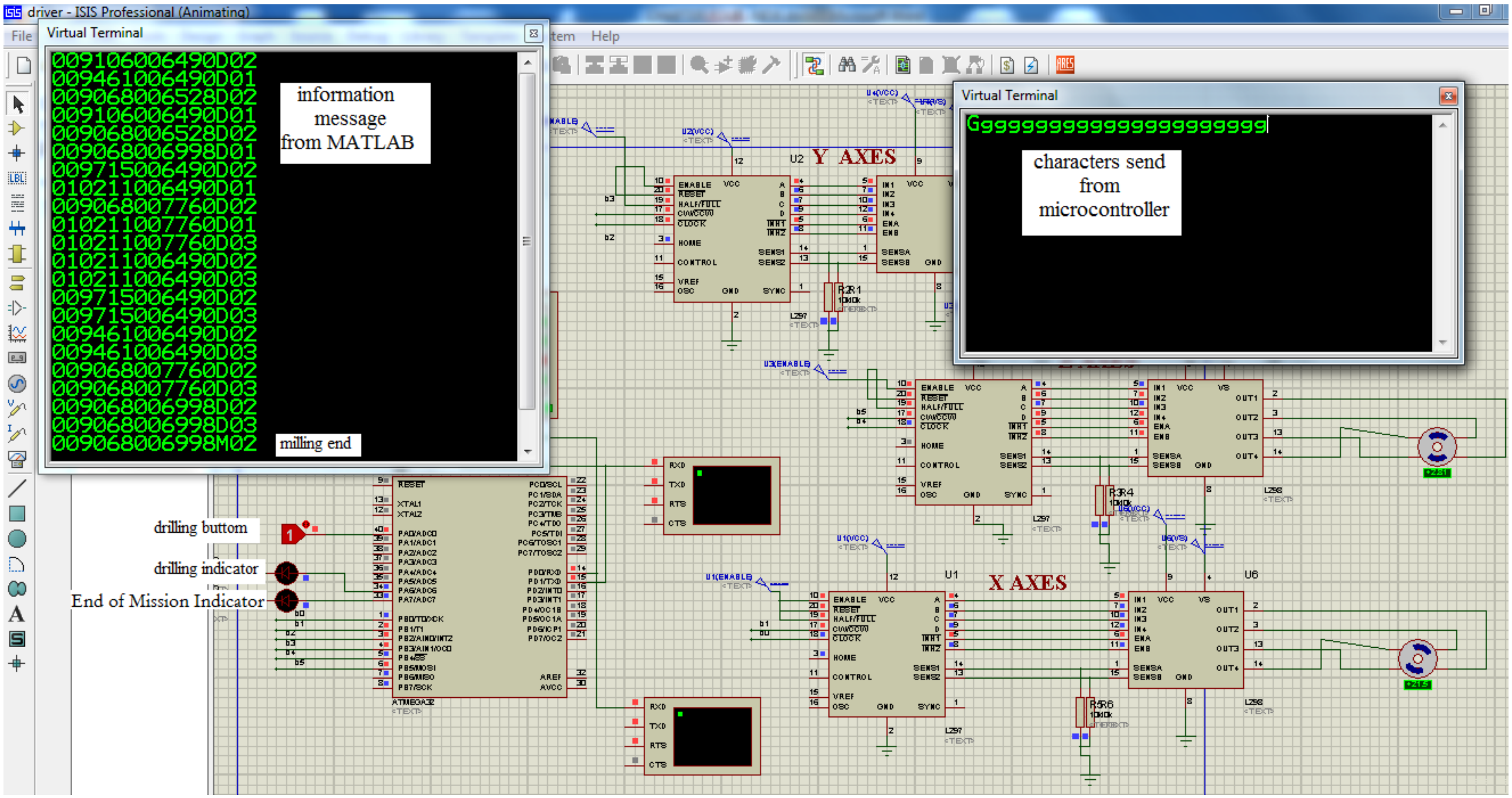


Figure 4.8: Execution of both milling and drilling processes in the proposed PCB CNC machine in Proteus ISIS

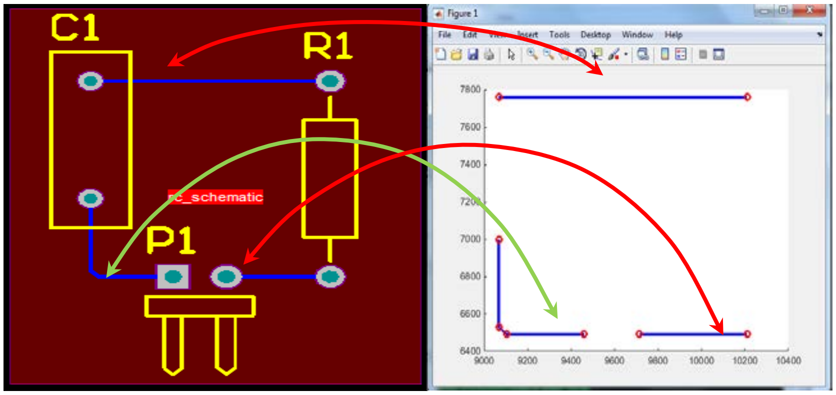


Figure 4.9: PCB generated from ALTIUM VS PCB generated after milling

4.4 The Sorted Coordinates Path planning Algorithm for Drilling Process

To start the drilling process, the drilling button (tactile switch) at the PCB CNC machine should be pressed were the Start/End of drilling process indicator is flashed once as in Figure 4.10. Therefore, the PCB CNC machine microcontroller starts receiving the drilling coordinates (generated by MATLAB platform) through the serial communication port as shown in Figure 4.11. After completion all the drilling coordinates, the end of drilling indicator is turned OFF as in Figure 4.11.It is worthy to note that the Y-coordinates were sorted increasingly first (in MATLAB m-file as shown in Figure 4.12 in the MATLAB command window) and then passed the completed (X, Y)-coordinates to the PCB CNC machine microcontroller to governs the coordinates motors movement as well as Drilling motor. In Figure (4.13) the generated drilling points for the RC circuit using path planning sorting coordinates algorithm is shown. Note that the drilling process starts by the connection header (P), the connected terminal of R1 with the header P, the connected terminal of C1 with the header P, and finally the second C1 terminal and R1 terminal respectively.

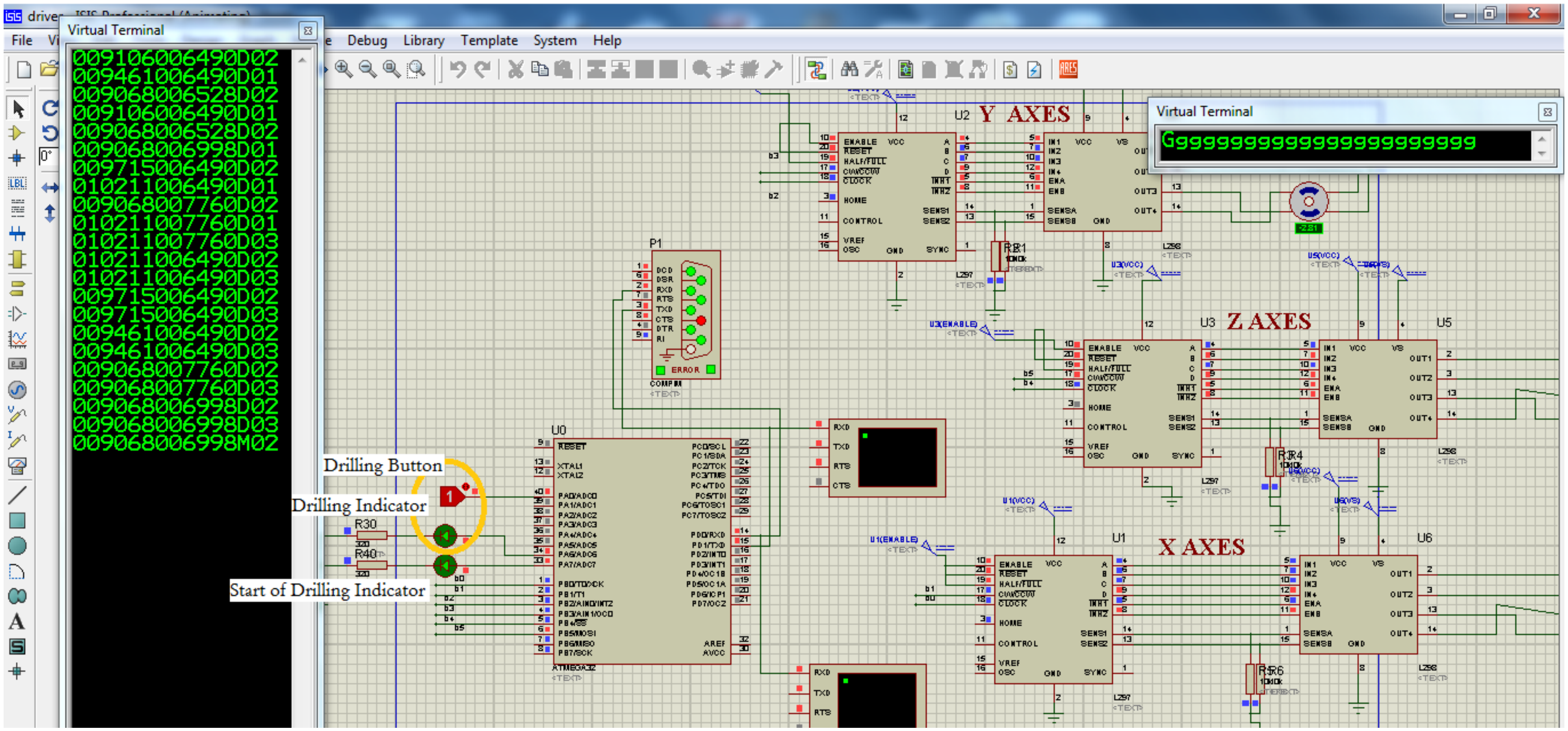


Figure 4.10: Resuming the process of drilling by pressing the drilling button

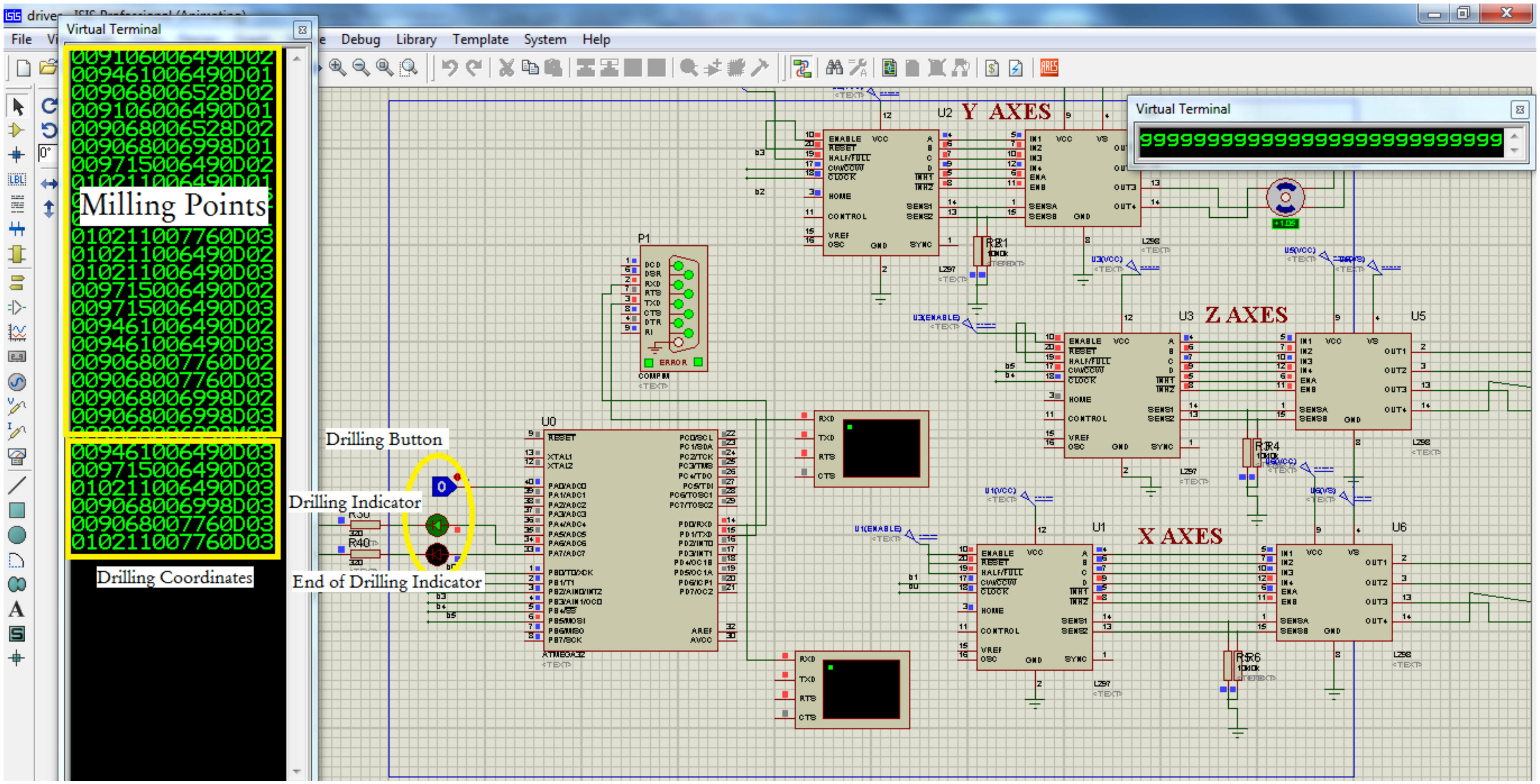


Figure 4.11: Completion of drilling process by completing the drilling coordinates where the end of drilling indicator is OFF

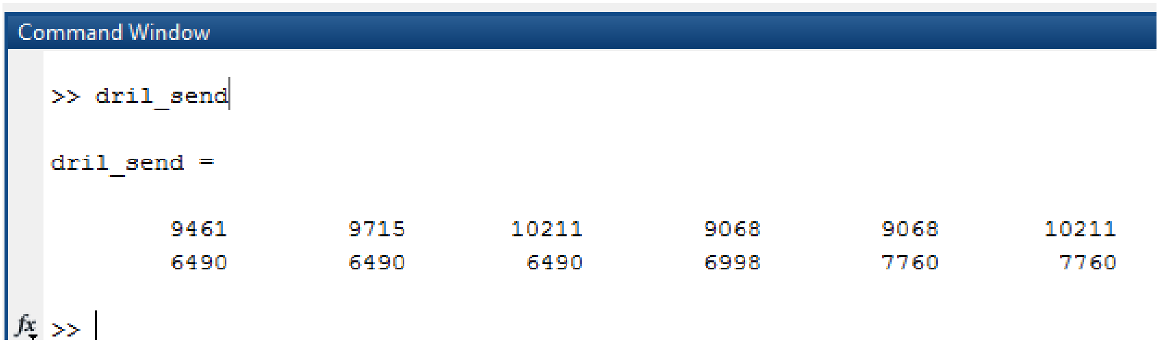


Figure 4.12: The complete Pathplanning drilling coodrdinates points stored at matrix (i.e. drill_send) in the MATLAB command Window

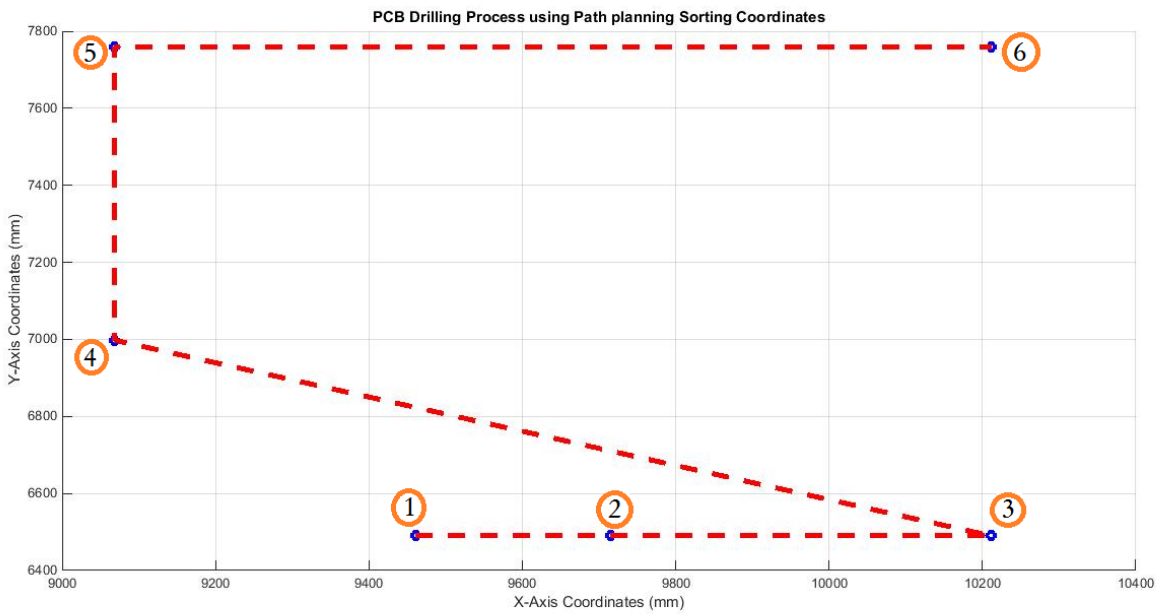


Figure 4.13: Drilling points plot by MATLAB using path planning sorting coordinates

CHAPER FIVE

CONCLUSION AND RECOMMENDATIONS

CHAPER FIVE

CONCLUSION AND RECOMENDATIONS

5.2 Conclusion

A low cost Mini PCB CNC Machine was designed and implemented by local components and with three stepper motors from scrapped computer parts.Atmega16/32 microcontroller was used to be the machine control and processing unit. An MATLAB-based programme was developed to analysis the generated Gerber file from most PCB designer software, where the serial communication interface was utilized to provide the required communication between the PC and the PCB CNC machine microcontroller. Moreover, Path Planning algorithm was applied by combinations of row by row and near neighbor techniques to generate the drilling coordinates.

The implemented PCB CNC machine prototype has maximum scale 50×50mm, where a large machine can be implemented easily by replacing the motor shafts with the suitable one. To reduce power consuming as well as protecting the motors from parasite charges, the associated Drivers should be enabled at motor movement. It is well-known that the motors use high current comparable to the microcontroller (one of the purpose of the drivers); therefore, an independent motors power supply should be designed. Moreover, the proposed PCB CNC machine handles only the PCB boards without considering the different track widths. It is worthy to note that the developed analytical MATLAB programme is only for Gerber file. It can be improved easily to analysis also image-based Artwork PCB.

5.3 Recomentation

To develop a complete PCB CNC machine the following recommendation can be achieved:

- The skeleton of PCB CNC machine can be made from aluminum bars and angles to be rigid enough, according to the standard dimensions of PCB CNC machine.
- The stepper motors can be replaced by the motors at the scrapped copier machines which have more torque and longer shaft where belts can be used to transfer the motor movement.
- With the mission indicator, a buzzer can be used for opto-sound indication.
- Auto-replacement of the drilling tools can be added where the PCB board has different drilling size.
- For large PCB size, an SD memory can be attached to the PCB CNC microcontroller to save the milling and drilling coordinates.
- The communication between the PC and the PCB CNC machine can be by USB protocol for more convenient and portability.
- The PCB CNC machine can be improved by considering the different track widths at a single PCB board.
- A MATLAB analytical programme G-code to C-Code can also be developed easily to be image-Code to C-Code for all the image-based PCB.

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APPENDIX A
ATMEGA16/32 MICROCONTROLLER DATASHEET

Features

- High-performance, Low-power Atmel® AVR® 8-bit Microcontroller
- Advanced RISC Architecture
  - 131 Powerful Instructions – Most Single-clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16 MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory segments
  - 16 Kbytes of In-System Self-programmable Flash program memory
  - 512 Bytes EEPROM
  - 1 Kbyte Internal SRAM
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/100 years at 25°C
  - Optional Boot Code Section with Independent Lock Bits
    In-System Programming by On-chip Boot Program
    True Read-While-Write Operation
  - Programming Lock for Software Security
- JTAG (IEEE std. 1149.1 Compliant) Interface
  - Boundary-scan Capabilities According to the JTAG Standard
  - Extensive On-chip Debug Support
  - Programming of Flash, EEPROM, Fuses, and Lock Bits through the JTAG Interface
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescalers and Compare Modes
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Four PWM Channels
  - 8-channel, 10-bit ADC
    8 Single-ended Channels
    7 Differential Channels in TQFP Package Only
    2 Differential Channels with Programmable Gain at 1x, 10x, or 200x
  - Byte-oriented Two-wire Serial Interface
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated RC Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby and Extended Standby
- I/O and Packages
  - 32 Programmable I/O Lines
  - 40-pin PDIP, 44-lead TQFP, and 44-pad QFN/MLF
- Operating Voltages
  - 2.7V - 5.5V for ATmega16L
  - 4.5V - 5.5V for ATmega16
- Speed Grades
  - 0 - 8 MHz for ATmega16L
  - 0 - 16 MHz for ATmega16
- Power Consumption @ 1 MHz, 3V, and 25°C for ATmega16L
  - Active: 1.1 mA
  - Idle Mode: 0.35 mA
  - Power-down Mode: < 1 µA

8-bit AVR® Microcontroller with 16K Bytes In-System Programmable Flash

ATmega16
ATmega16L

Rev. 2466T–AVR–07/10

APPENDIEX B
L297 DRIVER DATASHEET

SGS-THOMSON MICROELECTRONICS

L297
L297D

STEPPER MOTOR CONTROLLERS

- NORMAL/WAWE DRIVE
- HALF/FULL STEP MODES
- CLOCKWISE/ANTICLOCKWISE DIRECTION
- SWITCHMODE LOAD CURRENT REGULATION
- PROGRAMMABLE LOAD CURRENT
- FEW EXTERNAL COMPONENTS
- RESET INPUT & HOME OUTPUT
- ENABLE INPUT

DIP20 SO20

ORDERING NUMBERS : L297 (DIP20)
L297D (SO20)

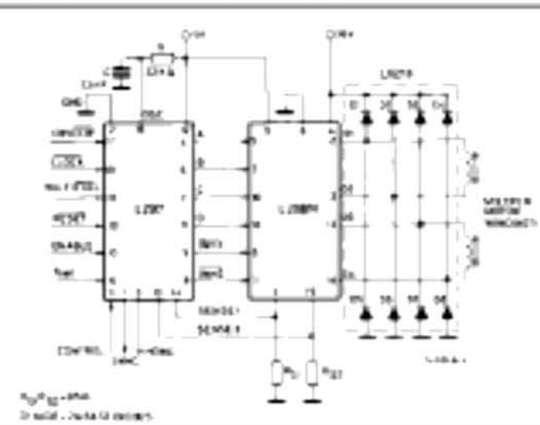
DESCRIPTION

The L297/A/D Stepper Motor Controller IC generates four phase drive signals for two phase bipolar and four phase unipolar step motors in microcomputer-controlled applications. The motor can be driven in half step, normal and wawe drive modes and on-chip PWM chopper circuits permit switch-mode control of the current in the windings. A feature of this device is that it requires only clock, direction and mode input signals. Since the phase are generated internally the burden on the microprocessor and the programmer is greatly reduced. Mounted in DIP20 and SO20 packages, the L297 can be used with monolithic bridge drives such as the L298N or L293E, or with discrete transistors and darlingtons.

ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_s	Supply voltage	10	V
V_i	Input signals	7	V
P_{tot}	Total power dissipation (T_{amb} = 70°C)	1	W
T_{stg}, T_j	Storage and junction temperature	-40 to + 150	°C

TWO PHASE BIPOLAR STEPPER MOTOR CONTROL CIRCUIT



APPENDIEX C
L298 DRIVER DATASHEET

L298

DUAL FULL-BRIDGE DRIVER

- OPERATING SUPPLY VOLTAGE UP TO 46 V
- TOTAL DC CURRENT UP TO 4 A
- LOW SATURATION VOLTAGE
- OVERTEMPERATURE PROTECTION
- LOGICAL "0" INPUT VOLTAGE UP TO 1.5 V (HIGH NOISE IMMUNITY)

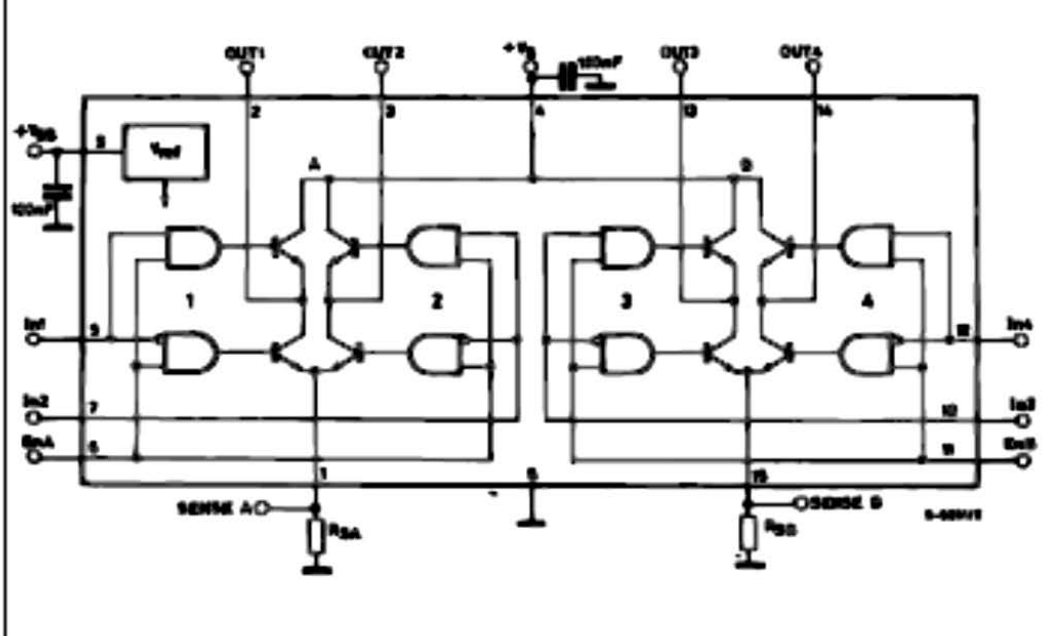
Multiwatt15 PowerSO20

ORDERING NUMBERS : L298N (Multiwatt Vert.)
L298HN (Multiwatt Horiz.)
L298P (PowerSO20)

DESCRIPTION

The L298 is an integrated monolithic circuit in a 15-lead Multiwatt and PowerSO20 packages. It is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage.

BLOCK DIAGRAM



APPENDIX D
A MATLAB PROGRAM FOR ANALYSIS GERBER FILE AND SENDING TO MACHINE CONTROL UNIT

```
%------------------------------------------------------------------------------
clear
PCB11.txt=['C:\Users\Public\Documents\Altium\AD13\Examples\Altium
Course\RC_circuit\Output\rc.txt'];
fid = fopen(PCB11.txt,'rt');
data=fread(fid);
chardata=char(data);
fclose(fid);
SER = serial('COM1','baudrate',9600);
SER.Timeout=0.1;
DRIL=[];dr=1;delet=[];dril_send=[];
%-------------------------------------------------------------------------------
l=length(chardata);
s_num=1;
j=1;
for i=1:1:l
ifisspace(chardata(i))
s_num=s_num+1;
        j=1;
continue
end
command(s_num,j)=chardata(i);
    j=j+1;
end
%---------------------------------------------------------------
ADD=findstr(chardata','ADD');
ADD_LENGTH=length(ADD);
[m,n]=size(command);
for i=1:ADD_LENGTH
Order_num=num2str(i+9);
D_order=['D',Order_num];
for j=1:m
tf=strncmp(command(j,:),D_order,3);
iftf~=0
D_position(i)=j;
end
end
D_position(length(D_position)+1)=m;
end
%----------------------------------------------------------------
for i=1:ADD_LENGTH
for j=D_position(i)+1:D_position(i+1)-1
```

```
    NL=command(j,:);
    X=findstr(NL,'X');
    Y=findstr(NL,'Y');
    D=findstr(NL,'D');

if X ~= 0
if Y~=0
        F=NL(X+1:Y-1);
        H=NL(Y+1:D-1);
        D_VALUE=NL(D:D+2);

else
        F=NL(X+1:D-1);
        D_VALUE=NL(D:D+2);

end
elseif Y ~= 0

   H=NL(Y+1:D-1);
   D_VALUE=NL(D:D+2);

elseif D ~= 0

   D_VALUE='D03';
end
   X_VALUE=F;
   Y_VALUE=H;
   D_VALUE;
   %=========================== DRAW PCB
if D_VALUE=='D01'
hold on
       x=str2num(X_VALUE);
       y=str2num(Y_VALUE);
plot([xx x],[yy y],'-b','linewidth',3);
plot([xx x],[yy y],'or','linewidth',2);
end
if D_VALUE=='D03'%====FOR PATH PLANNING CODE=====
                x=str2num(X_VALUE);
               y=str2num(Y_VALUE);
DRIL(1,dr)=x;
DRIL(2,dr)=y;
dr=dr+1;
end%=================END OF PATH PLANNINT DEFINITION
xx=str2num(X_VALUE);
yy=str2num(Y_VALUE);
    %========================================== END DRAW PCB

fopen(SER);
```

```
whileSER.BytesAvailable~=1

end
read=fscanf(SER)
fwrite(SER,X_VALUE)
fwrite(SER,Y_VALUE)
fwrite(SER,D_VALUE)
fwrite(SER,13);
fclose(SER);
  X_VALUE,Y_VALUE,D_VALUE
pause(0.5);
end
%
end
X_VALUE=F;
Y_VALUE=H;
D_VALUE='M02';
pause(0.5) %----<<<--------   to delay time for response
fopen(SER);
whileSER.BytesAvailable~=1

end
read=fscanf(SER)
fwrite(SER,X_VALUE)
fwrite(SER,Y_VALUE)
fwrite(SER,D_VALUE)
fwrite(SER,13);
fclose(SER);
X_VALUE,Y_VALUE,D_VALUE
%################PATH PLANNING ALGORITHM
CODE##########################
q=1;
while length(DRIL)~=0 %---------
del=1;
fordr=1:length(DRIL) %--- Search inside DRIL matrix
if DRIL(2,dr)==min(DRIL(2,:))% --- to find index of minimum item
DRIL(:,dr),delet(del)=dr;del=del+1;
end                          %----------------------------------
end
q=q+1
if rem(q,2)==0         %=========  even row
dril_send=[dril_send,[sort(DRIL(1,delet));DRIL(2,delet)]]
else                   % ======= odd row
dril_send=[dril_send,fliplr([sort(DRIL(1,delet));DRIL(2,delet)])] %fliplr==(flip left right)
end
DRIL(:,delet)=[]     %----- delet previous point
delet=[];
end
```

```
figure(2);grid on;hold on;
plot(dril_send(1,:),dril_send(2,:),'ob','linewidth',3);
plot(dril_send(1,:),dril_send(2,:),'--r','linewidth',3);
fopen(SER);
 % ======================  Send  DRIL points
for i=1:length(dril_send)

whileSER.BytesAvailable~=1

end
read=fscanf(SER);
kk=num2str(dril_send(1,i));
if length(kk)==5
kk=['0',kk];
elseif length(kk)==4
kk=['00',kk];
end
fwrite(SER,kk);
kk=num2str(dril_send(2,i));
if length(kk)==5
kk=['0',kk];
elseif length(kk)==4
kk=['00',kk];
end
fwrite(SER,kk);
fwrite(SER,'D03');
fwrite(SER,13);
 X_VALUE,Y_VALUE,D_VALUE
end
fclose(SER);
%###########################################################
```

APPENDIX E
BASCOM CODE FOR CONTROLLING MOTORS BY ATMEGA32 MICROCONTROLLER AND COMMUNICATING WITH MATLAB

```
$regfile = "m32def.dat"
$crystal = 8000000
$baud = 9600
Config Pina.0 = Input
Config Porta.7 = Output :Config Porta.6 = Output
Dim Var1 As String * 15 ,Varx As String * 6 , S As Integer , Vary As String * 6
Dim X As Integer , J As Long , I As Long , K As Byte , Sum As Long
Dim Z As Single , P As Long , X_valu As Long , Y_valu As Long
Dim W As Integer ,Vard As String * 3 , Var2 As String * 1 , Vardpre As String * 3
Dim Xx As Single ,Yy As Single , Del As Integer
Xx = 50 :Yy = 50
Dim X_steps As Long ,Y_steps As Long
ConfigPortb = Output
Portb = 0 : Porta.0 = 1 : Del = 20 : Vardpre = "D02"
Wait 5
Print "G";
Do
If Ischarwaiting() = 1 Then
 Input Var1 Noecho
Varx = Left(var1 , 6)
     Vary = Mid(var1 , 7 , 6)
Vard = Right(var1 , 3)
   '========================================        000080004000D01
 For X = 1 To 6 Step 1
     Var2 = Mid(varx , X , 1)
    W = Val(var2)
' W = Var2 - 48
    K = 6 - X
    J = 10 ^ K
     P = J * W
      Sum = Sum + P
    Next
X_valu = Sum
Sum = 0
    For X = 1 To 6 Step 1
     Var2 = Mid(vary , X , 1)
    W = Val(var2)
' W = Var2 - 48
```

```
     K = 6 - X
     J = 10 ^ K
      P = J * W
       Sum = Sum + P
     Next
Y_valu = Sum
Sum = 0
 If Vard = "M02" Then
   Porta.6 = 1
    While Pina.0 = 0
    Porta.7 = 0
    Wend
    Porta.7 = 1
  End If
GosubZtrans
GosubCalc
If Porta.6 = 1 Then
GosubGodown
GosubGoup
 End If
  Print "g";
End If
Loop
Ztrans:
 If Vard = "D01" And Vardpre = "D02" Then
GosubGodown
 End If
 If Vard = "D02" And Vardpre = "D01" Then
GosubGoup
 End If
 If Vard = "D03" Then
  Wait 3
  Else
Vardpre = Vard
  End If
Return
Calc:
Xx = X_valu - Xx :Yy = Y_valu - Yy : Yy = Yy / 100 : Xx = Xx / 100
X_steps = Xx * 14.0625
X_steps = X_steps / 0.7853
Y_steps = Yy * 14.0625
Y_steps = Y_steps / 0.7853
Xx = X_valu :Yy = Y_valu
If X_steps< 0 Then
 Portb.1 = 1
Else
Portb.1 = 0
End If
```

```
If Y_steps< 0 Then
Portb.3 = 1
Else
Portb.3 = 0
End If
Y_steps = Abs(y_steps)
X_steps = Abs(x_steps)
  P = 0
If Y_steps>X_steps Then
J = Y_steps / X_steps
   For I = 0 ToY_steps
         Portb.2 = 1
Waitms 10
         Portb.2 = 0
Waitms 10
  If P = J AndX_steps<> 0 Then
        Portb.0 = 1
Waitms 10
        Portb.0 = 0
Waitms 10
        P = 0
  End If
     P = P + 1
     Next
ElseifX_steps>Y_steps Then
      J = X_steps / Y_steps
   For I = 0 ToX_steps
         Portb.0 = 1
Waitms 10
         Portb.0 = 0
Waitms 10
   If P = J AndY_steps<> 0 Then
        Portb.2 = 1
Waitms 10
        Portb.2 = 0
Waitms 10
        P = 0
  End If
     P = P + 1
     Next
  End If
 Return
Godown:
  Portb.5 = 0
    For I = 0 To 49
    Portb.4 = 1
Waitms 10
    Portb.4 = 0
```

```
Waitms 10
   Next
   Return
Goup:
     Portb.5 = 1
  For I = 0 To 49
  Portb.4 = 1
Waitms 10
  Portb.4 = 0
Waitms 10
   Next
   Return
```