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Design, Control and Realization of a CNC Laser Engraving Machine

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Dedications

I dedicate this modest work

To my parents who have provided me with their encouragement love and understanding.

To my brother ADIL, my sisters AMINA, FARAH and DOUAA for their wholehearted support.

I am truly thankful and honored to have you as my family.

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Feriel

I dedicate this modest work

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Glossary

CNC: Computer Numeric Control

NC: Numeric Control

APT: Automatic Programmed Tools

MIT: Massachusetts Institute of Technology

DNC: Direct Numerical Control

CAM: Computer Aided Manufacturing

CIM: Computer Integrated Manufacturing

CPU: Central Processing Unit

EDM: Electrical Discharge Machines

LASER: Light Amplification by Stimulation Emission of Radiation

FAST: Functional Analysis System Technic

FAQ: Frequently asked questions

Introduction

In recent years, significant progress has been made in controlling electrical machines due to the revolution of industrial computer technology. We have seen the advent of digital controls utilizing CNC (computer numerical control) after the first generation of digital controls employing hard-wired logic. The CNC relies on a computer to control machine tool operations. Instructions are usually entered in a specific programming language and are then executed by the computer to control the movements and functions of the machine.

Nowadays, mechanical machines, including milling and lathes machines, cannot be suited to cut or engrave on sheets of material, and they have some disadvantages like high investment costs, more effort needed for maintenance, and high labor costs for programmers and operators.

Our project's fundamental goal is designing, controlling, and realizing a portable CNC laser engraving machine, which is a mechatronic system that integrates mechanical, electronic, and software components. It is for drawing that does not have the disadvantages of the classic CNC and holds the maximum advantages. Our machine can engrave on various surfaces depending on the power of the laser diode with greater precision and accuracy.

This model is for small scale, easy to use, low production costs, and easy to carry from one workstation to another. This is due to open-source software, the microcontroller board Arduino UNO based on the ATmega328P, the small stepper motors SM ITC-CNC-3, and the simple mechanisms to transfer the movement to the 4W laser.

To accomplish this objective, we have structured this thesis as follows: In the first chapter, we present a fundamental knowledge of CNC machines and especially give an overview of laser machines. In the second chapter, we perform a functional analysis to select the technological solutions. The third chapter presents the machine design using SolidWorks in the mechanical and electronic subsystems. The fourth chapter presents the software part, including the leading software needed for our machine. Finally, the last chapter is destined for the realization of our machine.

CHAPTER I

Fundamental Knowledge of CNC Machines

I.1 Introduction

Electrical machine control has advanced significantly in recent years. These advancements are mostly the result of the industrial computer technological revolution, which has enabled the development of efficient numerical solutions with the ability to apply increasingly sophisticated algorithms. In this chapter, we present a fundamental knowledge of CNC machines, especially giving an overview of the laser machine.

I.2 History of CNC machining

Simple balls of clay were transformed into vases on potter's wheels 3,500 before Christ, making this the oldest use of a machine tool. Artisans using a pedal or crank produce the handcrafted items. Thousands of similar pieces were manufactured with more powerful machine tools in place of the unique items that artisans created on pedal or crank lathes.

The new digital machines are computer-controlled, precise, and quick, and they take the place of artisanal skills. By using data transmitted by a punched card, Falcon and Jacquard's work at the end of the 18th century showed that it was possible to control the actions of a machine.

In 1805, this method was extended to their looms, which are known as the origins of numerical control, and as a result, the industrial application of NC came to be associated with the advancement of electronics. John Parsons began producing helicopter blades for the US Air Force in Michigan in 1947. He employed a technique that involved drilling many hundred holes tightly spaced apart to form his templates near the theoretical contour. However, Parsons discovered that his approach was too approximate and that only continuous machining in three dimensions would be adequate when the US Air Force asked him to build even more intricate forms for its upcoming supersonic aircraft. He tasked the Massachusetts Institute of Technology (MIT) with creating servo-controls that could operate a machine while taking intermittent commands from a card reader in the spring of 1949.

In September 1952, the Servo Mechanism Laboratory at MIT hosted the official presentation of this machine, a prototype Cincinnati milling machine with a vertical spindle intended to perform simultaneous movements along three axes, in September 1952.

The concept was called numerical control since it was founded on mathematical data. Making the first Numerical Control Machine Tools operational would require several more years of significant money from the US Air Force and the assistance of MIT academics.

The history of CNC machines demonstrates the relevance of software development. Technological advances in the previous few decades have resulted in a rapid change in the manufacturing industry, this evolution was as follow **[1, 2].**

The evolution of the CNC machines along the years are given in Table 1:

Table 1: Evolution of CNC machining

1954	Bendix produced the first industrial NC after acquiring Parsons' patent.
1955	In Font du Lac (Wisconsin), the American manufacturer Giddins & Lewis marketed the first Numerical Control Machine Tools.
1959	The NC's appearance at the Hannover Fair in Europe. The APT (Automatic Programmed Tools) programming language is introduced by MIT.
1960	Introduction of the DNC (Direct Numerical Control) system.

1964	In France, Télémécanique Electrique launches the NUM 100 NC based on Téléstatic relays
1968	NC employs integrated circuits, making them more compact and powerful. Kearney and Trecker (USA) put the first machining center on sale.
1972	Mini calculators have taken the place of hard-wired logic, and NC has evolved into CNC.
1976	Development of microprocessor-based NCs
1984	The emergence of advanced graphic functions and conversational programming ushered in the era of computer-aided manufacturing (CAM).
1986	NCs are integrated into communication networks, ushering in the era of flexible manufacturing (CIM: computer-integrated manufacturing).
1990	Development of 32-bit microprocessor-based NCs.

I.3 Computerized Numerical Control (CNC)

The CNC imposes its technology on the machining industry. It was initially possible to take an important step in the automation of traditional machine tools such as milling machines and drilling machines by controlling the functioning of a machine from the instructions of a program without the direct interaction of the operator during its execution **[3]**.

I.4 CNC machine

A CNC machine is a fully or partially automatic machine that receives orders via codes. When the machine tool has a numerical control capable of determining the coordinates of the points constituting a trajectory. A CNC machine's first role is to generate movements. After treatment, it will receive location, speed, and acceleration measurements and provide numerical output instructions. It offers more computer power and higher use flexibility than a programmable controller **[4]**.

I.5 Difference between NC and CNC

NC (numeric control) and CNC (computer numeric control) are technologies used in various sectors and factories to control multiple machining tools. The fundamental distinction between both controls is that NC is the traditional control that allows the utilization of information already entered in the machining process. CNC, on the other hand, goes a step by offering greater flexibility and capabilities **[5].**

I.6 Operating principle of CNC machine

The role of CNC machines, in general, is to apply a machining process or more than one process; this benefit is obtained by providing energy and information. Unlike the classic machines, there is no information process; therefore, the operator has to deliver the movement orders himself. However, in CNC machines, the operator has to enter the machining parameters and select the operating mode.

In order to replace the expertise of the operator, we need to establish a system that can recognize the technological equipment and take into consideration the geometric data of the machine structure to generate the movement orders according to the G-Code, which is an ISO computer language used for programming various CNC machines entered by the operator who also supervises the machine during its work to prevent it from any unexpected problem or undetectable by the machine technology. As Figure 1 shows, CNC machines can be broken down into three parts: an operative part, a control part, and an operator panel.

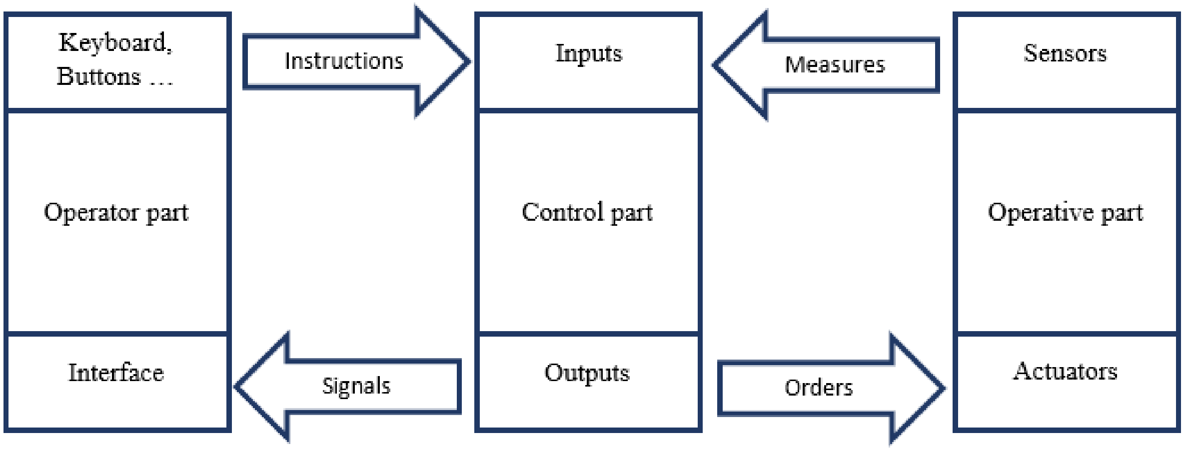


Figure 1: CNC machine modelization

I.6.1 Operative part

Includes a basic machine equipped with actuators that provide spindle rotation, the movement of the trolleys, control of the position of the carriages, cutting lubrication, etc. Associated peripherals can provide warehousing allowing automatic tool change.

I.6.2 Control part

Provides three major functions, program implementation and visualization, connection with the position sensors and the various motors of the machine, Information processing, and calculations.

I.6.3 Operator panel

A terminal from which NC operation is carried out. It is designed to be integrated into the machine, recessed into a cabinet, and contains an interface for communication.

I.7 Components of CNC machines

CNC systems include the six major components mentioned below **[5]**:

I.7.1 Input Devices

Floppy Disk Drive, USB Flash Drive, Serial Communication, Ethernet Communication, Conversational Programming.

I.7.2 Central Processing Unit/ Machine Control Unit

The CPU is the heart of a CNC system. It accepts information from memory as part of the program. This information is decoded and converted into position control and velocity signals. It also monitors the movement of the control axis or spindle and takes corrective action when it deviates from the programmed values.

I.7.3 Machine Tool

The operative part of a machine.

I.7.4 Driving System

The requirement is that the driving system responds precisely to the programmed instructions. The motor is directly or indirectly coupled to the machine lead screw via a gearbox to move the machine slide or spindle. Servomotors are electromechanical devices that generate precise degrees of rotation. Servomotors are also known as control motors because they are used to control a mechanical system. Servomotors have accurate speed, torque, and direction control capabilities.

Three types of electric motors are commonly used.

Permanent Magnet Stepper: PM steppers have rotors made of permanent magnets that interact with the electromagnets in the stator to generate rotation and torque. PM steppers typically have low power requirements and can generate more torque per input power unit.
Variable Reluctance Stepper: Permanent magnets are not used to construct VR stepper rotors. They are made of plain iron and look like gears, with protrusions or "teeth" around the circumference of the rotor. The teeth lead to VR steppers with extremely high angular resolution; even so, this precision is usually at the expense of torque.
Hybrid Synchronous Stepper: HS stepper rotors combine the best characteristics of both PM and VR steppers. An HS motor's rotor contains a permanent magnet core, while the circumference is made of plain iron and has teeth. As a result, a hybrid synchronous motor has both high angular resolution and high torque.

I.7.5 Feedback Devices

The two most common types of feedback devices are:

Positional Feed Back Devices

- Linear Transducers: a device put on the machine table to measure the actual displacement of the slide in such a way that backlash of screws, motors, etc., would not cause any inaccuracy in the feedback data.
- Rotary Encoders: a device for measuring angular displacement. It cannot directly detect linear displacement; hence errors may occur owing to screw and motor backlash,

Velocity Feedback Device

The real speed of the motor can be calculated using the voltage generated by a tachometer installed on the motor shaft. The DC tachometer voltage is compared to the command voltage corresponding to the desired speed. The voltage difference is employed to trigger the motor to eliminate the mistake.

I.7.6 Display Unit

It is an Interface between the machine and the operator.

I.8 Types of CNC Machining

There are five types of CNC machining, which are performed by five different types of CNC machines **[6]**.

I.8.1 CNC Lathes and Turning Machines

CNC lathes and turning machines are distinguished by their ability to rotate (turn) materials while machining. These machines feed cutting tools linearly around the spinning bar stock, removing material around the perimeter until the desired diameter is reached.

I.8.2 CNC Milling Machines

CNC milling machines are defined by their ability to rotate cutting tools while remaining stationary with the material workpiece/block. They may create a variety of shapes, including face-milled and peripheral-milled features.

I.8.3 CNC Electrical Discharge Machines (EDM)

A CNC electric discharge machine (EDM) manipulates materials into a specific shape by using highly controlled electrical sparks. It's also known as spark eroding, die sinking, spark machining, and wire burning.

I.8.4 CNC Plasma Cutting Machines

Materials are also sliced using CNC plasma-cutting equipment. However, they execute this procedure with a computer-controlled high-powered plasma (electronically ionized gas) torch. Plasma torches perform similarly to a handheld, gas-powered welding torch (up to 10,000 degrees Fahrenheit) but can reach temperatures up to 50,000 degrees Fahrenheit. To cut the material, the plasma torch melts through the workpiece.

I.8.5 CNC Laser Machines

CNC laser machines employ a pointed router with a highly concentrated laser beam to precisely cut, slice, or etch materials. The laser heats the material, causing it to melt or vaporize and leaving a cut. The material is typically in sheet form, and the laser beam goes back and forth over the material to generate a precise form.

I.9 Types of lasers

There are three main types of laser engraving **[7].**

I.9.1 CO2 lasers

A carbon-mixed laser is used for gas laser cutting, often known as CO2 laser cutting. It is made practical by electrically stimulating a carbon dioxide mixture.

I.9.2 Crystal Laser

Crystal laser cutting is a technique that uses lasers made from Nd: YAG and Nd: YVO. These crystals belong to the solid-state category and allow for exceptionally high-powered cutting. It works with both metals and nonmetals.

I.9.3 Fiber lasers

Fiber lasers have a high-power level, ranging from 20 to 50 watts. Furthermore, because of the high level of filtration of monochromatic light beams, they offer a wide spectrum of material compatibility. As a result, they are extremely popular marking machines.

I.10 Advantages and disadvantages of CNC laser machines

Laser cutting provides a number of advantages, but it also has some downsides. Below, we'll talk about a few of them **[8].**

I.10.1 Advantages

- Engineers choose laser cutting services because of the numerous benefits they provide. The benefits of laser cutting are flexibility, precision, repeatability, and speed.
- Laser cutting does not necessitate the exchange of equipment for each individual cut. The same configuration can be used to cut a variety of forms from the same material thickness.
- Laser cutting is far faster than previous mechanical cutting processes. This is especially true for more intricate cuts.

I.10.2 Disadvantages

Although laser cutting makes parts in practically every industry, it has some drawbacks. Before going to laser cutting, consider the requirement for expertise to ensure that the cutting quality meets the standards people expect from this technology. And also, consider metal thickness constraints because, when compared to other thermal cutting technologies, laser cutting is not appropriate for cutting particularly thick plates. The machinery available determines the maximum suitable thickness.

I.11 Literature review

The literature review provides the scope for our project. Djamel SMAINI et al.**[3]** designed a CNC machine based on Arduino UNO and Universal G Code Sender software to implement the G code and control the tool. Hamza ADAIKA et al.**[4]** They realized a mini-CNC lathe machine with a control system based on LINUXCNC and used SOLIDWORKS 2016 software to model their machine. Kumar et al. **[11]** fabricated a portable laser cutting and engraving machine, which the Arduino CNC controls. They used the ELEKSMAKER Software to convert the graphical image into a G code language. Reza et al. **[12]** concentrated on the industry's sketching component while describing the construction of a CNC controller-based plotter. This machine was programmed using the Arduino IDE, and the G code was generated using the CAMotics software. The concept of creating a cheap router system that can interpolate three axes at once was given by Jayachandraiah et al. **[13]**. This low-cost prototyping is made possible by combining the functions of the standard PC interface with a CNC system built on a microcontroller in an embedded system based on Arduino. The present literature was carried out to design, control, and realization of portable CNC laser engraving machine; this machine is precise, able to process or engrave complex drawings, doesn't require much space, doesn't require an operator with high qualifications, and also very cheap for purchasing and maintenance. Our machine is based on an Arduino UNO board and uses an open-source LaserGRBL, Arduino IDE, and Grbl firmware for controlling and managing laser engraving operations.

I.12 Conclusion

In this chapter, we presented an overview of CNC machines citing the core elements of the CNC system. After that, we discussed the types of laser engraving machines and concluded with a literature review.

CHAPTER II

Functional Analysis

II.1 Introduction

In this chapter, we look at the basic stage of the design of our CNC laser-engraving machine. The first step is to study, analyze and dissect the product envisaged to make it as competitive as possible and give it the maximum characteristics. To ensure this stage, the product must be defined as a functional whole, ensuring a certain number of functions.

II.2 Definition of functional analysis

The AFNOR NF X 50-101 standard defines the Functional Analysis approach, which consists of researching, ordering, characterizing, prioritizing, and enhancing the functions of a product.

Functional analysis is an approach used to precisely define a product's needs and functions (system). Several tools, often graphical, describe what a product should do.

II.3 Role of functional analysis

Before looking for solutions, the functional analysis allows:

- The description of the user's need in relation to a system in terms of functions to be guaranteed.
- The description of the technological choices imposed on the system in terms of constraints.
- The description of the system in terms of service or usage functions (satisfaction of the need) and constraint functions (technical solutions retained which meet the constraints).
- The optimization of the need on the economic and technical level (Obtaining the best service at the lowest cost.).
- Innovate systems.

II.4 External functional analysis

The external analysis identifies the system's interactions with external factors. This must result in the identification of the intended external functions and properties. The provider's audit outlines the exterior parts of the system as well as the initial primary 'contexts' to be considered **[14]**. In our study we chose to use the Horned Beast diagram to define the need and the Octopus diagram to express the need, and we finalized this external analysis by drawing up the functional specification.

II.4.1 Definition of need by Horned Beast diagram

The horned beast diagram makes the essential condition that supported the development of the CNC laser-engraving machine. A diagram is a tool that depicts the need that the system met as the head of an animal with horns and a protruding tongue. The animal's two horns provided answers to the design considerations of "Whom is the product useful for?" and "What does it have an effect on?" The animal's head stood in for the created product. Moreover, the tongue determined the product's goal **[15]**.

The horned beast diagram is given in Figure 2:

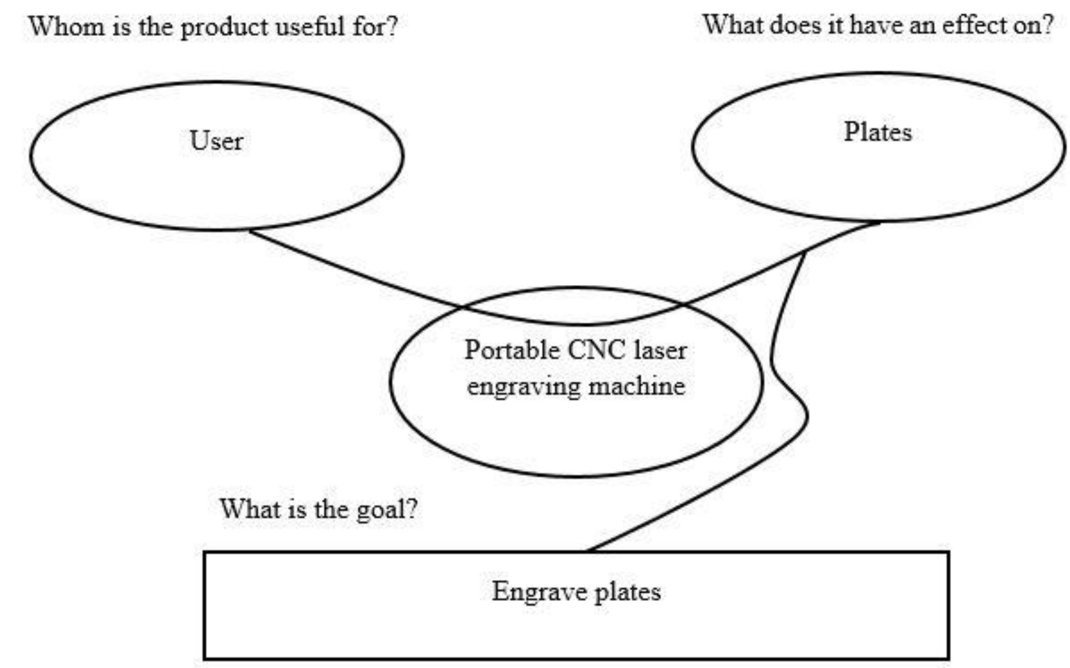


Figure 2: Horned beast diagram

The statement of need: "The product serves the user by allowing him to engrave the plates."

II.4.2 Expression of need by Octopus diagram

The octopus diagram's role is to specify the relationships that exist between elements of the system environment. To do this, we will define the service functions, separated into main FP functions, and FC constraint functions.

The Octopus diagram is given in Figure 3:

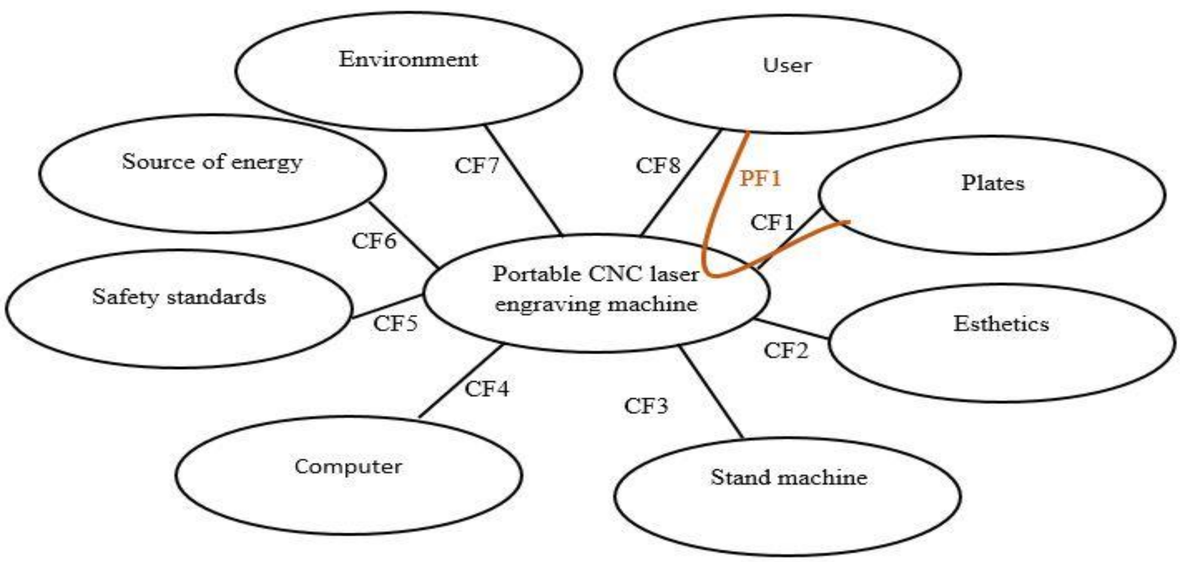


Figure 3: Octopus diagram

The Octopus diagram's functions are given in Table 2:

Table 2: Octopus diagram's fonctions

	Principal function
PF1	To engrave the plates according to the user's choice automatically
	Constraint function
CF1	To adapt to the dimensions and the material of the plates
CF2	To be aesthetically pleasing
CF3	To support the weight of the machine
CF4	To be controlled by the computer
CF5	To comply with safety standards
CF6	To supply with electrical energy
CF7	To have low impact on environment
CF8	To be easy for the user to operate and maintain

II.4.3 Functional specifications

It is a document (in the form of a table) which details what is expected precisely from our product; the functional specifications of the machine are given in Table 3:

Table 3: Functional specifications

	Functions	**Criterion**	**Levels**	**Flexibility**
PF1	Allow to engrave the plates according to the user choice automatically.	Engraving speed	S = X (m/s)	1
		Engraving acceleration	A = X (m/s^2)	1
CF1	To adapt to the dimensions of the plates.	Length	L = 1000 (mm)	0
		Width	W = 600 (mm)	0
		Thickness	T = 15 (mm)	0
CF2	To be aesthetically pleasing	Color	Black and Grey	0
		Form	Modern compatible shape	0
CF3	To support the weight of the machine	Weight supported		0
CF4	To be controlled by the computer.	Communication	Serial communications	
		Synchronization	Pack of N command lines	
CF5	To comply with safety standards.	Safety standards	ISO 16090- 1:2017	
CF6	To supply with electrical energy.	Voltage	220 (V) AC	0
		Frequency	50 (Hz)	0
CF7	To have low impact on the environment.			
CF8	To be easy for the user to operate.	Software interface	Computer screen	

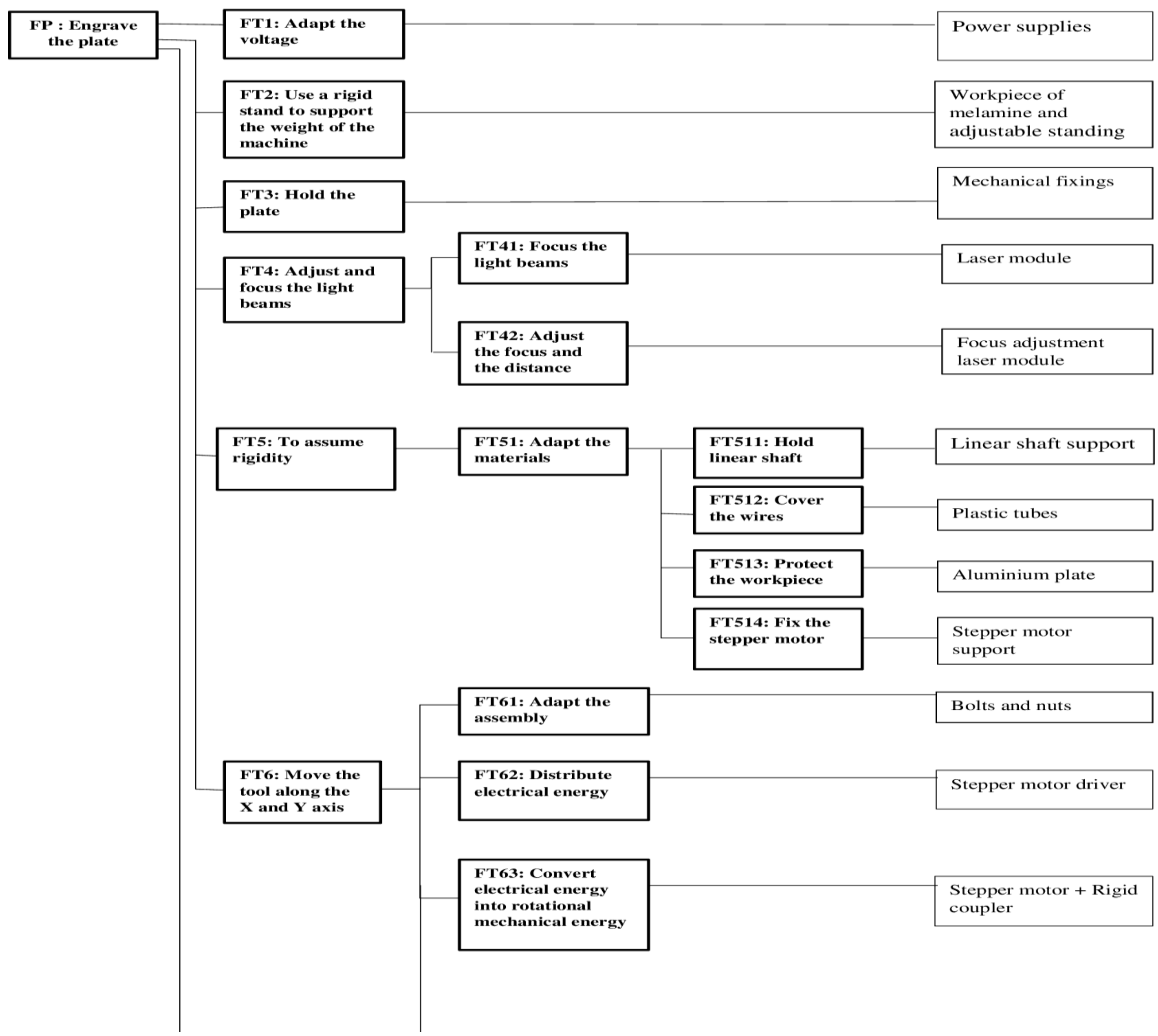
The External Functional Analysis carried out previously, which consists of formalizing the need and the diagram of the Octopus, which illustrates the relations between the system and its external environment, still needs to be improved to know the system. For this, we carry out an Internal Functional Analysis.

II.5 Internal functional analysis

The internal functional analysis entails determining the internal functions of the product or the functions that each of its components is responsible for carrying out **[16]**.

II.5.1 Functional Analysis System Technic (F.A.S.T) diagram

The F.A.S.T diagram's role is to decompose the main functions of a design problem into technical functions and then into technological solutions. In addition, the FAST method helps to think about the problem objectively and helps determine the scope of the project by illustrating the logical relationships between functions. Arranging functions logically in a FAST diagram allows participants to determine all required functions.



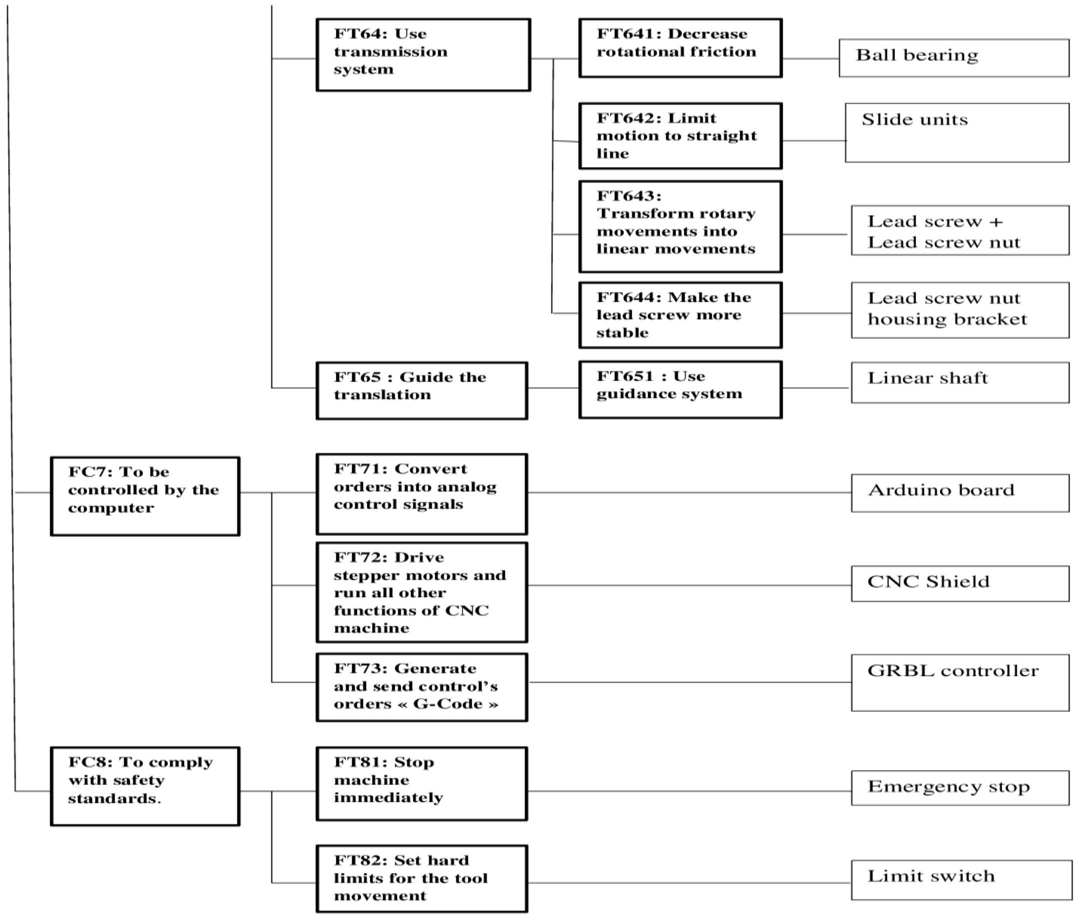


Figure 4: FAST diagram

II.5.2 Technical specification

The result of the internal functional analysis is presented in a document entitled technical specifications. It mainly focuses on the properties of the internal parts and subsystems of our system; the technical specifications of the machine are given in Table 4:

Table 4: Technical specifications

Components		**Quantity**
Laser source	Laser-module 12V 4W 450NM	1
	Focus adjustment laser module	1
	Power supply unit	1
Control card	Arduino Uno	1
	USB cable	1
	ARDUINO CNC Shield V3	1
Stepper motor driver	A 4988	3
Stepper motor	SM ITC-CNC-3	3
	SM support NEMA -16/17	2
	SM support NEMA -16/17 plate	1
	SM shaft coupler	3
Limit switch		4

Ball bearing 8×22×7mm	3
Slide unit for X axis 12ø	2
Slide unit for Y axis 12ø	2
SK 12 linear bearing rail shaft support ø 12mm	4
T8 lead screw nut housing bracket	3
T8 lead screw 3D printer parts	3
Linear shaft	4
Emergency stop	1
Power supply unit (for motors)	1
Electrical wire	30
Workpiece (melamine)	4

II.6 Cost study

Cost study is the process of determining the components of a system's cost. the main objective of this study is to uncover reducing cost, the costs of the machine components are given in Table 4:

Table 4: Cost study

Components		**Quantity**	**Unit cost (DA)**
Laser source	Laser-module _ 12V 1W 450NM	1	28000
	Focus adjustment laser module	1	5000
	Power supply unit	1	1200
Control card	Arduino Uno	1	3200
	USB cable	1	450
	ARDUINO CNC Shield V3	1	1100
Stepper motor driver	A 4988	3	550
Stepper motor	SM ITC-CNC-3	3	3300
	SM support NEMA -16/17	2	650
	SM support NEMA -16/17 plate	1	500
	SM shaft coupler	3	450
Limit switch		4	300
Ball bearing 8×22×7mm		3	150
Slide unit for X axis 12ø		2	4000
Slide unit for Y axis 12ø		2	2900
SK 12 linear bearing rail shaft support ø 12mm		4	650
T8 lead screw nut housing bracket		3	1200
T8 lead screw 3D printer parts		3	2500
Linear shaft		4	873
Emergency stop		1	650
Power supply unit (for motors)		1	1650
Electrical wire		30	450
Workpiece (melamine)		4	4400

II.7 Conclusion

In this chapter, we presented the definition, the role of the FA, the external FA to specify the relation between our machine and the external elements, and the internal FA to conclude with the choice of the technological solutions, which is the goal of the FA.

CHAPTER III

Software Analysis

III.1 Introduction

Our machine is divided into two parts, the control part, and the operational part. The control part of automation and the decision center gives orders to the operative part and receives its reports; our control part is in the Arduino UNO board, control the three SMs using the CNC shield and the SM's drivers A4988 and controls our laser module using the laser's driver board.
Every control part works simultaneously with the software; in our case, our machine needs three pieces of software to work correctly, so in this chapter, we will present the definition, objective, description, and configuration of each one.

III.2 Arduino IDE

Here is an overview of the Arduino IDE.

III.2.1 Definition

The Arduino Integrated Development Environment, or Arduino Software (IDE) - contains a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions, and a series of menus. It connects to the Arduino hardware to upload programs and communicate with them. The Arduino IDE is suitable for different operating systems, such as Windows, Mac OS X, and Linux **[17]**.

III.2.2 Objective

The objective of the Arduino IDE is to write and upload the code to the Arduino board **[17]**.

III.2.3 Description

The code written by Arduino IDE is called a sketch. After connecting the Arduino board to the IDE, the sketch is saved with the "ino" extension **[17]**.

The interface of the IDE is given in Figure 5:

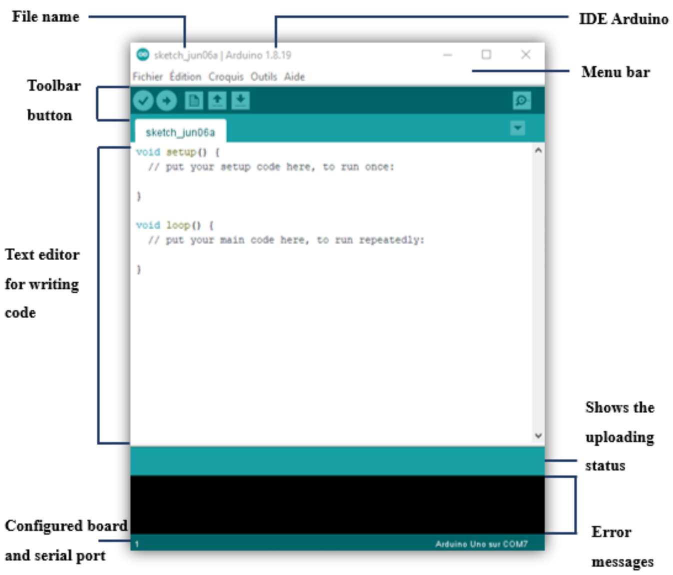


Figure 5: Arduino IDE interface

Now we will discuss the sections of the Arduino display.

Toolbar button: The toolbar icons are Verify, Upload, New, Open, Save, and Serial monitor; all icons are given in Figure 6:

Figure 6: Toolbar icons

The role of each icon is explained in Table 5:

Table 5: Toolbar icons roles

Icons	Role
Upload	Compile the code written and run it, after that send the compiled code to the Arduino board, after selecting the correct board and serial port.
Open	Open a created file and present it in the actual window.
Save	Save the sketch written.
New	Create a new sketch.
Verify	Check errors in the code's compilation or the code itself.
Serial monitor	Debugging and testing out concepts or to communicate directly with the Arduino board.

Menu bar: The menu bar windows are File, Edit, Sketch, Tools and Help.

The options of each window and its role are presented in Table 6:

Table 6: Menu bar options and roles

File	
Options	**Role**
New	Open new window and keeping the previous sketches.
Open	Opens a browsed file from the laptop memory.
Open recent	Opens a list of recent files.
Sketchbook	Stores the opened files and opens a selected one in another editor.
Examples	Opens a different example for better understanding the code.
Close	Closes the selected code window.
Save	Saves the current sketch.
Save as	Saves the current sketch with the possibility of changing its name.
Page setup	Sets the page margins, orientation, and size of printing.
Print	Prepares the sketch for printing according to the specification of the page setup.
Preferences	Customize the IDE settings.
Quit	Closes all the opened sketches windows.
Edit	
Options	**Role**
Undo	Reverses the last modification of the sketch while editing.
Redo	Repeats the last modification of the sketch while editing.
Cut	Removes the selected text from the sketch.
Copy	Creates a duplicate copy of the selected text from the sketch.
Copy for forum	Copy the selected text to the clipboard.
Copy as HTML	Copy the selected text as HTML to the clipboard.
Paste	Paste the selected text to the clipboard at the position of the cursor.
Select all	Selects all the text of the sketch.
Go to line	Moves the cursor to the specified line number.
Comment/Decomment	Put or remove the comment mark at the beginning of the specified line.
Increase indent	Add the space at the start of the specified line.
Decrease indent	Remove the space at the start of the specified line.
Increase font size	Increases the font size of the written text.
Decrease font size	Decreases the font size of the written text.
Find	Find the specified text.
Find next	Highlights the next word, which has specified in the 'Find...' window.
Find previous	Highlights the previous word, which has specified in the 'Find...' window.
Sketch	
Options	**Role**
Verify/Compile	Check for the errors in the code while compiling.
Upload	Configure the code to the specified board through the port.
Upload using programmer	Override the Bootloader that is present on the board.
Export compiled binary	Allows saving a .Hex file and can be kept archived.
Show sketch folder	Opens the folder of the current code written or sketch.
Include library	Includes various Arduino libraries.
Add file	Add the created file in a new tab on the existing file.

Tools	
Option	**Role**
Auto format	Format the written code.
Archive sketch	Archive the current sketch in the zip format.
Fix encoding and reload	Fix the inconsistency between the operating system char maps and editor char map encoding.
Manage libraries	Shows the updated list of all the installed libraries.
Serial monitor	Allows the exchange of data with the connected board on the port.
Serial plotter	Display the serial data in a plot.
WiFi101/WiFiNINA firmware updater	Check and update the Wi-Fi Firmware of the connected board.
Board	Select the board connected from the list of boards.
Processor	Displays the processor according to the selected board.
Port	Shows the virtual and real serial devices present on our machine.
Get board info	Gives the information about the selected board.
Programmer	Select the hardware programmer while programming the board.
Burn bootloader	The Bootloader is present on the board onto the microcontroller. The option is useful when we have purchased the microcontroller without the bootloader. Before burning the bootloader, we need to make sure about the correct selected board and port.
Help	
Options	**Role**
Getting started	Online and offline information about Arduino.
Environment	
Troubleshooting	
Reference	
Find reference	
Frequently asked questions (FAQ)	
Visit Arduino.cc	
About Arduino	

III.2.4 Configuration

We need to choose the right type of Arduino board by clicking on the menu bar **Tools / Board / Arduino UNO,** as shown in Figure 7:

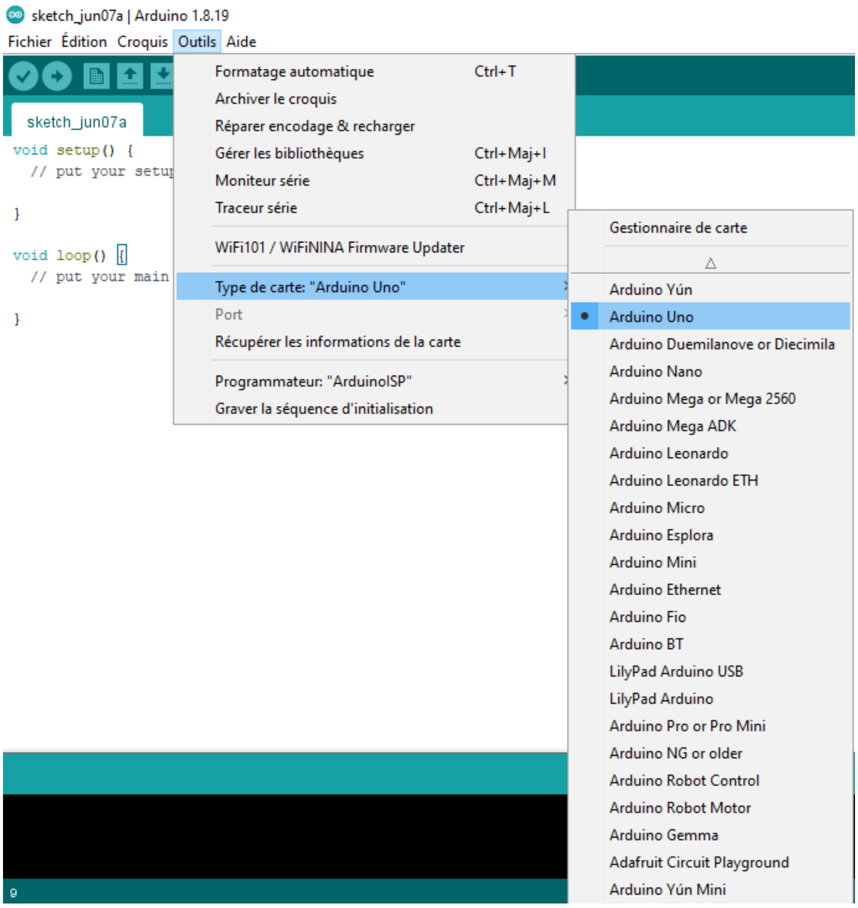


Figure 7: Choosing the board type

In addition, we choose the right port in which our board is connected by clicking on the menu bar **Tools / Port** as shown in Figure 8:

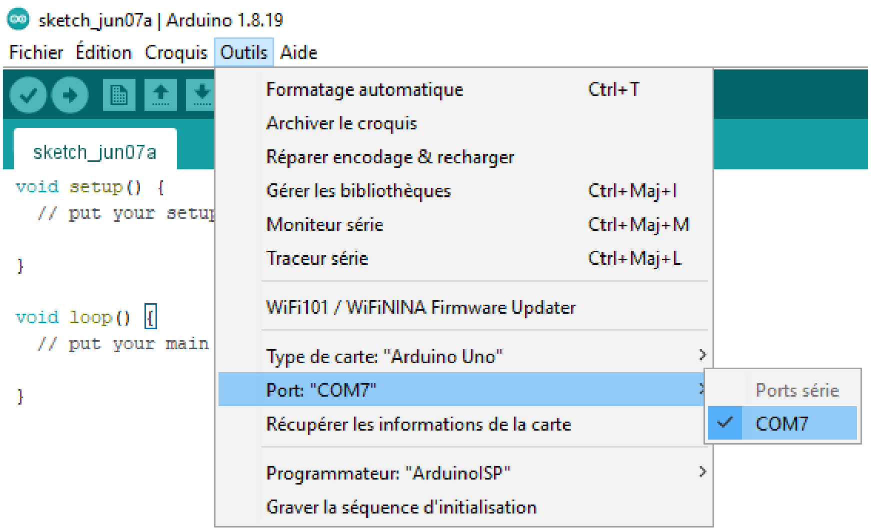


Figure 8: Choosing the port

III.3 Grbl

Here is an overview of the Grbl firmware.

III.3.1 Definition

GRBL is an open-source firmware developed for Arduino-based CNC systems and is commonly used in hobbyist and CNC projects **[18]**.

III.3.2 Objective

The Grbl firmware has many roles and functions, such as **[18]**:

- G-Code interpretation: Grbl is interpreted in real-time the G-Code, which is a standardized programming language that specifies tool movements, speeds, and other parameters; the result of this interpretation is motor movements and control signals.
- Motor control: Grbl controls the stepper motors of the CNC machine by generating pulses and signals accordingly to the instructions of the G-Code and the specified parameters like the speed and acceleration of the axes.
- Coordinate transformation: Grbl converts the coordinate values from the G-Code into motor steps or micro steps.
- Real-Time overrides: Grbl allows real-time changing of some parameters during the operating time, like the spindle speed in a CNC milling machine or cutting speed in a CNC engraving machine.
- Limit and homing switches: Grbl ensures two security functions homing and limit switching; the homing function defines the origin of the machine coordinates, and the limit switches prevent the machine from collapsing when the tool reaches the limits of the workspace by inverting the rotation direction of the stepper motor.
- Error handling and status reporting: Grbl monitors detect errors during operation and report errors in the user interface.

III.3.3 Description

On our machine, we used version 'Grbl v1.1, a version released on 25/08/2019, which is header files written in C language and the examples 'grblUpload' that will be later uploaded to the Arduino board. Like is shown in Figure 9 below **[18]**:

examples	26/08/2019 01:13	Dossier de fichiers	
config	26/08/2019 01:13	Fichier source C Header	49 Ko
coolant_control	26/08/2019 01:13	C Source File	4 Ko
coolant_control	26/08/2019 01:13	Fichier source C Header	2 Ko
cpu_map	26/08/2019 01:13	Fichier source C Header	12 Ko
defaults	26/08/2019 01:13	Fichier source C Header	29 Ko
eeprom	26/08/2019 01:13	C Source File	6 Ko
eeprom	26/08/2019 01:13	Fichier source C Header	2 Ko
gcode	26/08/2019 01:13	C Source File	62 Ko
gcode	26/08/2019 01:13	Fichier source C Header	11 Ko
grbl	26/08/2019 01:13	Fichier source C Header	5 Ko
jog	26/08/2019 01:13	C Source File	2 Ko
jog	26/08/2019 01:13	Fichier source C Header	1 Ko
limits	26/08/2019 01:13	C Source File	19 Ko
limits	26/08/2019 01:13	Fichier source C Header	2 Ko
main	26/08/2019 01:13	C Source File	5 Ko
motion_control	26/08/2019 01:13	C Source File	19 Ko
motion_control	26/08/2019 01:13	Fichier source C Header	3 Ko
nuts_bolts	26/08/2019 01:13	C Source File	6 Ko
nuts_bolts	26/08/2019 01:13	Fichier source C Header	4 Ko
planner	26/08/2019 01:13	C Source File	27 Ko
planner	26/08/2019 01:13	Fichier source C Header	7 Ko
print	26/08/2019 01:13	C Source File	5 Ko
print	26/08/2019 01:13	Fichier source C Header	2 Ko
probe	26/08/2019 01:13	C Source File	3 Ko
probe	26/08/2019 01:13	Fichier source C Header	2 Ko
protocol	26/08/2019 01:13	C Source File	38 Ko
protocol	26/08/2019 01:13	Fichier source C Header	2 Ko
report	26/08/2019 01:13	C Source File	25 Ko

Figure 9: grblUpload

III.3.4 Configuration

The Grbl firmware does not have an interface; for that reason, we needed a third software that works as a Grbl controller, so all the Grbl configuration will be done in the next part.

III.4 LaserGRBL

Here is an overview of the LaserGRBL.

III.4.1 Definition

LaserGRBL is a software application used in conjunction with the GRBL firmware to operate laser-based CNC machines **[19]**.

III.4.2 Objective

The main function of LaserGRBL is to convert image file from various formats like JPEG, BMP, PNG, SVG, and DXF into G-Code instructions that the laser engraver understand and execute.

LaserGRBL allows users to adjust images by tracing, resizing, and editing. In addition, the user can modify some parameters like laser power, speed, and focus.

LaserGRBL also provides a real-time simulation feature, allowing users to preview the engraving process before actually executing it **[19]**.

III.4.3 Description

Now we will discuss the sections of the LaserGRBL display; the LaserGRBL interface is given in Figure 10 **[19]**:

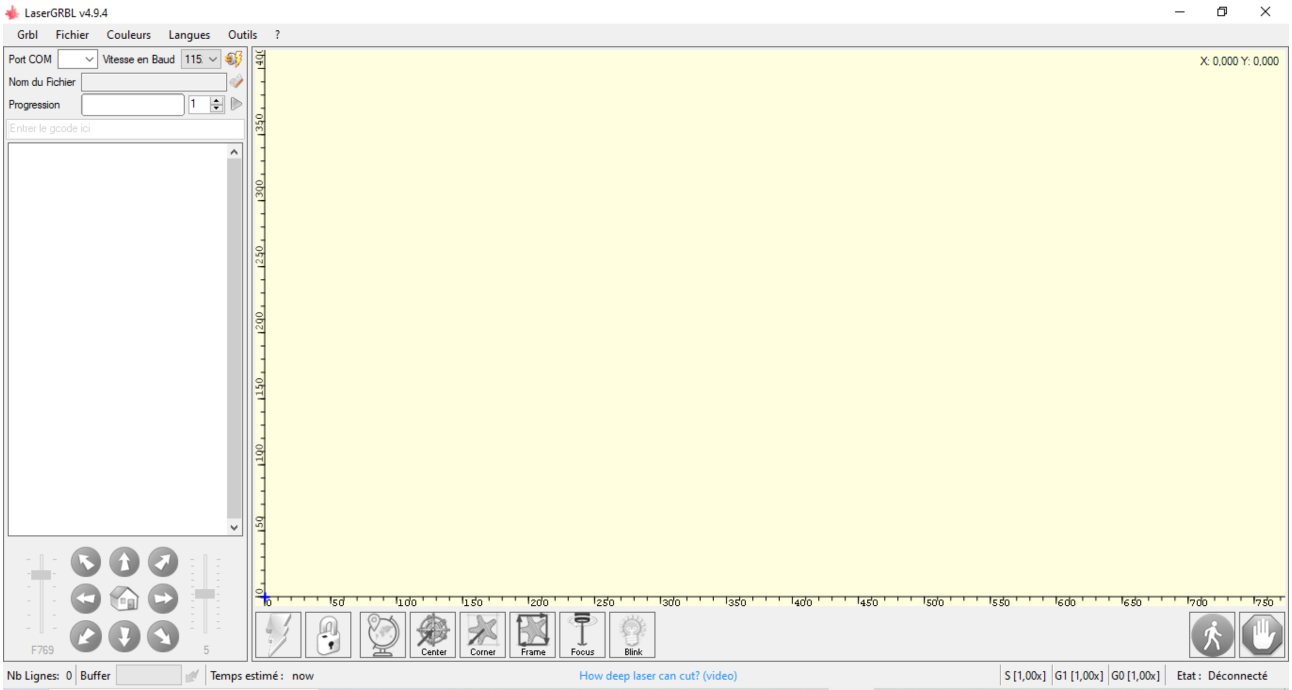


Figure 10: LaserGRBL interface

<u>*Toolbar button*</u>: Here are the options of the LaserGRBL interface and their options presented in table 7 below:

Table 7: Toolbar button explication

Grbl	
Option	**Role**
Connect	Connect the Arduino board to the software.
Reset	Erases all the executed lines of G-Code and stop the motor's movement and the laser.
Unlock	When you click reset, the software will be locked, the user can unlock it by clicking this option.
Grbl Configuration	Allows to adjust all the Grbl parameters according to the machine geometry.
Settings	Allows to adjust certain parameters, which are independent of the machine geometry like enabling the PWM.
Material DB	Allows to adjust certain parameters, which are independent of the machine geometry like enabling the PWM.
Hotkeys	Shows a list of shortcuts and their functions.
Exit	Closes the software.
File	
Option	**Role**
Open file	Allows to import a created file from different format like GCODE, Raster Image, Vector image and LaserGRBL Project.
Append File	Allow to open two overlapping files.
Reload Last File	Allow to open the last created file.
Quick Save	Allows to save the G-Code of the project.
Save (Advanced Options)	Allow to export the generated G-Code to be edited by another editor.
Save Project	Allows to save the project in (.Ips) format, which can be modified or executed only by laser engraver machines.
Send To Machine	Allows to send the G-Code generated to the machine connected to the laptop to execute it.
Send From Position	Allows to send the G-Code generated to the machine connected to the laptop to execute it from an initial point.
Colors	
Option	**Role**
Blue Laser	Changes the path's color to red.
Red Laser	Changes the path's color to bleu.
Dark	Change the themes of the interface.
Hacker	
Nighty	
Language	
Option	**Role**
English	Changes the language of the software interface according to the language spoken in that country.
Italian	
Spanish	

French	
German	
Danish	
Brazilian	
Russian	
Chinese (simplified)	
Chinese (traditional)	
Slovak	
Hungarian	
Czech	
Polish	
Greek	
Turkish	
Romanian	
Dutch	
Tools	
Option	**Role**
Install CH340 Driver	Installs the drivers of CH340 chipset, it is useful for CH340 chipset-based boards.
Flash Grbl Firmware	Installs the Grbl firmware in the Arduino boards without passing by the Arduino IDE.
Help	
Option	**Role**
Auto update	Allow the software to update itself when connected to the internet and a new update is available.
Open session log	Shows the history of the engraved images.
Activate extended log	Allows to create a text file, in which all the engraving images will be saved in that file since its creating date.
Help on line	Redirects the user to the official website of LaserGRBL to find a detailed explication of the user interface.
LaserGrbl FAQ	Redirects the user to the official website of LaserGRBL to find answers to the most common questions about LaserGRBL software usage.
LaserGrbl Community	Redirects the user to the Facebook page of LaserGRBL.
Donate!	Allows the user to donate the LaserGRBL community.
License	Shows the license of the installed version of the software.

III.4.4 Configuration

As we mentioned before, the Grbl firmware will be configured by the LaserGRBL software, so in this part, we will explain the window of the Grbl configuration and the role of each element.

The window of the Grbl configuration is shown in Figure 11:

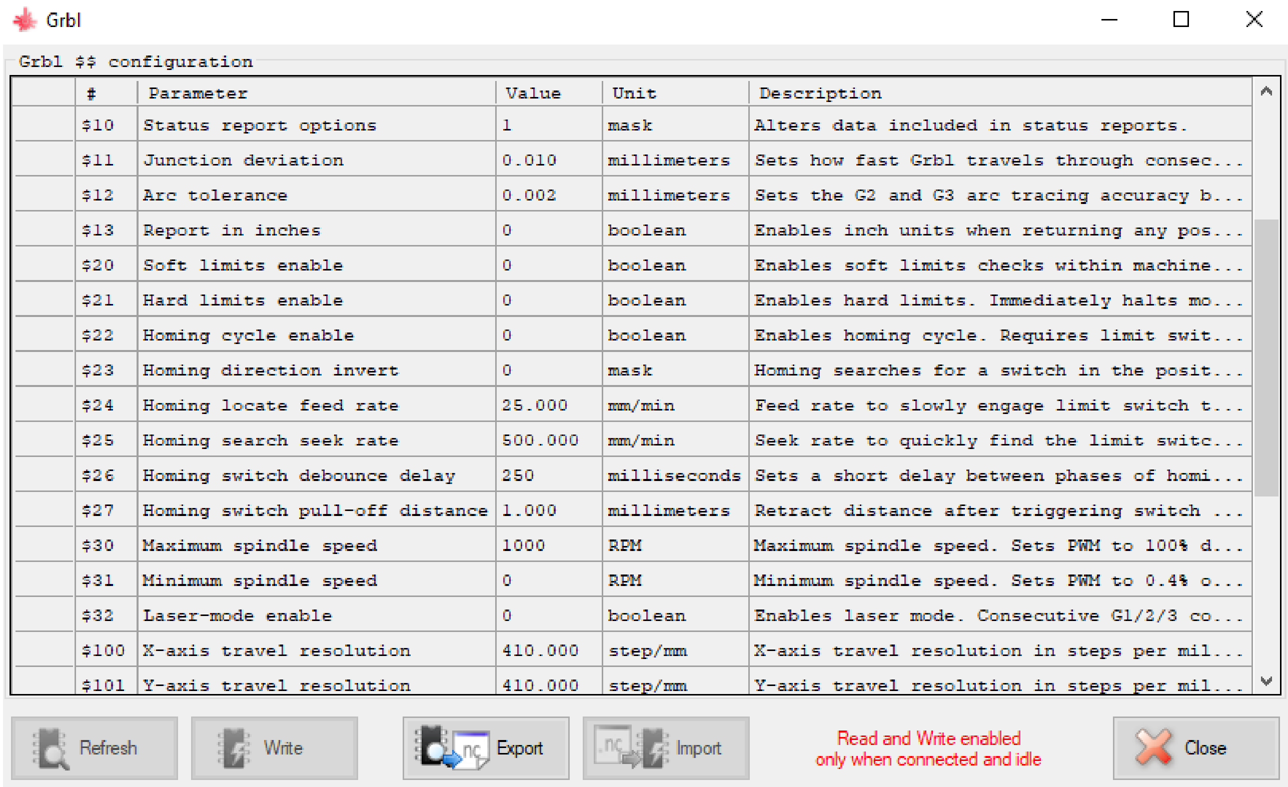


Figure 11: Grbl configuration window

Table 8 shows all the parameters and its role that the software can present by clicking **Grbl / Grbl Configuration**:

Table 8: Grbl configuration explication

Sign	Parameter	Value	Unit	Description
$0	Step pulse time	10	microseconds	Sets time length per step.
$1	Step idle delay	25	microseconds	Sets a short hold delay when stopping to let dynamics settle before disabling steppers.
$2	Step pulse invert	0	mask	Inverts the step signal.
$3	Step direction invert	0	mask	Inverts the direction signal.
$4	Invert step enable pin	0	boolean	Inverts the stepper driver enable pin signal.
$5	Invert limit pins	0	boolean	Inverts the all of the limit input pins.
$6	Invert probe pin	0	boolean	Inverts the probe input pin signal.
$10	Status report options	1	mask	Alters data included in status reports.
$11	Junction deviation	0.010	millimeters	Sets how fast Grbl travels through consecutive motions. Lower value slows it down.
$12	Arc tolerance	0.002	millimeters	Sets the G2 and G3 arc tracing accuracy based on radial error.
$13	Report in inches	0	boolean	Enables inch units when returning any position and rate value that is not a settings value.

$20	Soft limits enable	0	boolean	Enables soft limits checks within machine travel and sets alarm when exceeded.
$21	Hard limits enable	1	boolean	Enables hard limits.
$22	Homing cycle enable	0	boolean	Enables homing cycle.
$23	Homing direction invert	0	mask	Homing searches for a switch in the positive direction.
$24	Homing locate feed rate	25.000	mm/min	Feed rate to slowly engage limit switch to determine its location accurately.
$25	Homing search seek rate	500.000	mm/min	Seek rate to quickly find the limit switch before the slower locating phase.
$26	Homing switch debounce delay	250	milliseconds	Sets a short delay between phases of homing cycle to let a switch debounce.
$27	Homing switch pull-off distance	1.000	millimeters	Retract distance after triggering switch to disengage it.
$30	Maximum spindle speed	1000	RPM	Maximum spindle speed.
$31	Minimum spindle speed	0	RPM	Minimum spindle speed.
$32	Laser-mode enable	0	boolean	Enables laser mode.
$100	X-axis travel resolution	410.000	step/mm	X-axis travel resolution in steps per millimeter.
$101	Y-axis travel resolution	410.000	step/mm	Y-axis travel resolution in steps per millimeter.
$102	Z-axis travel resolution	410.000	step/mm	Z-axis travel resolution in steps per millimeter.
$110	X-axis maximum rate	1500.000	mm/min	X-axis maximum rate.
$111	Y-axis maximum rate	1500.000	mm/min	Y-axis maximum rate.
$112	Z-axis maximum rate	1500.000	mm/min	Z-axis maximum rate.
$120	X-axis acceleration	10.000	mm/sec^2	X-axis acceleration.
$121	Y-axis acceleration	10.000	mm/sec^2	Y-axis acceleration.
$122	Z-axis acceleration	10.000	mm/sec^2	Z-axis acceleration.
$130	X-axis maximum travel	500.000	millimeters	Maximum X-axis travel distance from homing switch.
$131	Y-axis maximum travel	500.000	millimeters	Maximum Y-axis travel distance from homing switch.
$132	Z-axis maximum travel	500.000	millimeters	Maximum Z-axis travel distance from homing switch.

By clicking on any case in the Value column, we can modify the value of the corresponding parameter.

III.5 Conclusion

Through this chapter, we have presented the definition, objective, and description of each software used in our machines.

CHAPTER IV

Detailed Machine Design

IV.1 Introduction

Our machine is a mechatronic system composed of three subsystems, mechanical, electronic, and software subsystem (discussed in the previous chapter). In this chapter, we will present the 3D design of the machine with SolidWorks and the mechanical details of each of the X and Y axis in the mechanical subsystem. In the electronic subsystem, we will present the electrical circuit with its components and the simulation of the machine using Proteus.

IV.2 Electronic Subsystem

The electronic subsystem of a CNC laser engraver based on the Arduino Uno board is responsible for controlling and coordinating various components of the engraver to achieve precise laser engraving operations. It provides the necessary interfaces and functionalities to drive the laser module, control the movement of the engraving platform, and handle user inputs.

IV.2.1 Electronic Components

Here are the electronic components used in our machine with their roles.

Arduino Uno Board: The Arduino Uno serves as the central control unit of the engraver. It is a microcontroller board based on the ATmega328P chip, offering a wide range of digital and analog input/output pins. The Arduino Uno runs the engraver's firmware, which includes the code responsible for interpreting G-code commands and controlling the engraver's operations.

In our machine, we used Arduino UNO R3; the technical specifications of the board are given in Table 9:

Table 9: Arduino UNO board technical specifications

Board	Name	Arduino UNO R3
	SKU	A000066
Microcontroller	ATmega328P	
USB connector	USB-B	
Pins	Built-in LED Pin	13
	Digital I/O Pins	14
	Analog input pins	6
	PWM pins	6
Communication	UART	Yes
	I2C	Yes
	SPI	Yes
Power	I/O Voltage	5V
	Input voltage (nominal)	7-12V
	DC Current per I/O Pin	20 mA
	Power Supply Connector	Barrel Plug
Clock speed	Main Processor	ATmega328P 16 MHz
	USB-Serial Processor	ATmega16U2 16 MHz
Memory	ATmega328P	2KB SRAM, 32KB FLASH, 1KB EEPROM
Dimensions	Weight	25 g
	Width	53.4 mm
	Length	68.6 mm

CNC shield: The CNC shield is an expansion board specifically designed for Arduino Uno and similar microcontroller boards. It is commonly used in CNC (Computer Numerical Control) systems and provides a convenient way to control stepper motors and other components in CNC applications.

The CNC shield offers other features that make it suitable for CNC machines, like GRBL compatibility, limit switch support, PWM control, and convenient pin headers.

In our machine, we used a V3 CNC shield; the technical specifications of the shield are given in Table 10:

Table 10: CNC shield V3 board technical specifications

Shield Type	CNC Shield
Model	A4988 shield
Compatible	0.9 GRBL
Axis Support	4 Axis Support
Dimensions	5*4*1 cms
Weight	15 grams

Laser Module: The laser module is the primary tool used for engraving. It typically consists of a laser diode, driver circuitry, and cooling components. The Arduino Uno, in conjunction with appropriate laser driver circuits, controls the laser module to emit laser beams of varying power and intensity to perform the engraving process.

In our machine, we used an LT-20W-A laser module; the technical specifications of the laser are given in Table 11:

Table 11: LT-20W-A laser module technical specifications

Optical power	4W(±0.5W)	**Module size**	35*35*95mm
Input	12V 1.6V	**Module weight**	146g
Wavelength	450nm(±10nm)	**Module material**	Aluminum alloy
Focus length	Adjustable	**Input interface**	XH2.54-3P socket
PWM modulation	Support 5V PWM modulation	**Application**	Engraving / Cutting

Stepper Motor: Stepper motors are designed to move in discrete steps or increments; each step corresponds to a specific angular or linear displacement, allowing for precise control over the motor's position.

In our machine, we used a NEMA 17 stepper motor; the technical specifications of the motor are given in Table 12:

Table 12: NEMA 17 stepper motor technical specifications

Drive system	Unipolar
Step angle	1.8° full step / 0.9° half-step
Phase/Windings	4/2
Voltage & Current	12V at 1.33A
Resistance per Phase	30 ohms
Inductance per Phase	23 mH
Holding Torque	2000 g-cm
Detent Torque	220 g-cm max
Weight	0,24 kg
Max continuous power	3 W
Rotor Inertia	22 g-cm2
Bearings	Ball
Leads	45,72 cm (18 in)
Insulation resistance	>100 MΩ at 500VDC
Dielectric strength	500V 50Hz/minute
Mounting hole space diagonal	4,3942 cm (1,73 in)
Mounting screws	3 mm diameter / 05 mm pitch
Shaft diameter	5 mm (0.197 in)
Motor footprint	4,318 cm (1,7 in * 1,7 in)
Motor height	3,81 cm (1,5 in)
Ambient temperature	10°C to +55°C

<u>*Stepper Motor Drivers:*</u> CNC engravers often use stepper motors to control the movement of the engraving platform along multiple axes. Stepper motor drivers interface with the Arduino Uno and provide the necessary power and control signals to drive the stepper motors accurately. These drivers receive instructions from the Arduino Uno to move the engraving platform to specific positions in a controlled manner.

In our machine, we used A4988 stepper motor drivers; the technical specifications of the driver are given in Table 13:

Table 13: A4988 stepper motor driver technical specifications

Operating voltage range	8 to 35 V
Continuous current per phase	No cooling: 1.2A
Continuous current per phase	With cooling: 2 A
Logic voltage range	3 to 5.5 V
Microstep resolutions	1/2, 1/4, 1/8, 1/16
Form factor	Fully assembled
PCB Dimensions	15.24 x 20.32 mm (0.6 in * 0.8 in)

In the A4988 driver, there are three pins dedicated to microstep resolution MS1, MS2, and MS3; we can enable each one of them by installing a jumper down the driver; the table X below shows the microstep resolution system according to the enabled pins:

Table 14: Microstep resolution system

MS1	MS2	MS3	Microstep Resolution
Low	Low	Low	Full step 1/1
High	Low	Low	Half step 1/2
Low	High	Low	Quarter step 1/4
High	High	Low	Eighth step 1/8
High	High	High	Sixteenth step 1/16

Limit Switches: Limit switches are used to detect the physical boundaries of the engraving platform's movement. They provide feedback to the Arduino Uno, allowing it to prevent the platform from exceeding its defined limits, ensuring safe and accurate operation.

The technical specifications of the limit switches used in our machine are given in Table 15:

Table 15: Limit switch technical specifications

Weight	20 g
Dimensions	10.00 mm * 30.00 mm * 5.00 mm

Power Supplies: An appropriate power supply is required to provide the necessary voltage and current for all the electronic components. The Arduino Uno, stepper motor drivers, laser module, and other peripheral devices each have their specific power requirements, which must be met for reliable and safe operation.

In our machine, we have two power supplies, one for the motors and the second for the laser module; the technical specifications of each power supply are given in Table 16:

Table 16: Power supplies technical specifications

Motor's Power Supply	
Model	S-60-12
AC Input	110/220V ± 15%
DC Output	12V 5A
Laser's Power Supply	
Model	S-24-12
AC Input	110/220V ± 15%
DC Output	12V 2A

IV.2.2 Electronic circuit

All these electronic components are connected in one circuit; here is the electronic circuit of our machine done by the free printed circuit design software FRITZING, represented in Figure 12:

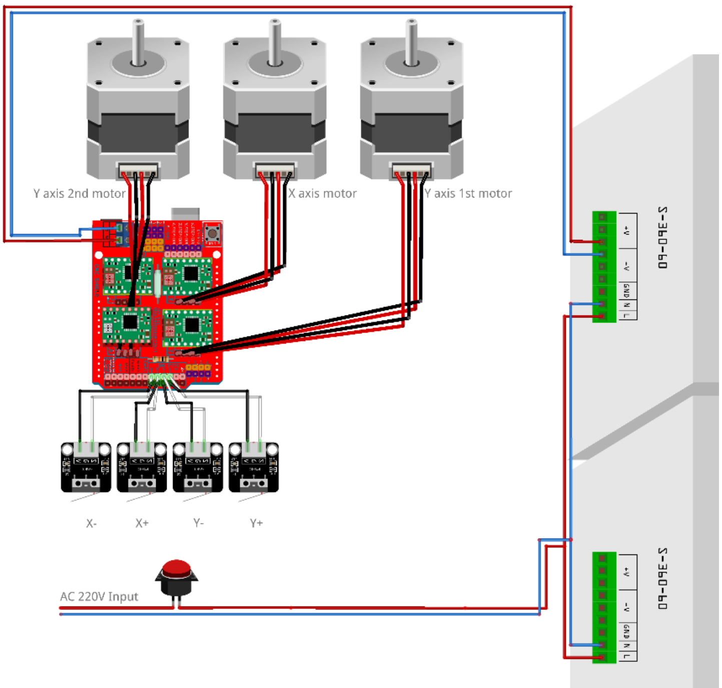


Figure 12: Electronic circuit by Fritzing

IV.2.3 Electronic circuit simulation

We have established a simulation of the electronic circuit using Proteus 8 software, the steps of the circuit making are given in Table 17:

Table 17: Circuit making steps

Steps	Operation
1	Including Arduino UNO board device
2	Creating three A4988 driver devices
3	Labeling the three A4988 drivers
4	Creating the child sheet of the three drivers with the two controllers L297 and L298
5	Creating the outputs of the Arduino board and labeling them according to the Arduino UNO GRBL pinout
6	Including the three bipolar stepper motors
7	Including the parameters of the stepper motors according to the datasheet of the stepper motor (Nominal voltage, Step angle, Maximum RPM, Coil resistance and Coil inductance)
8	Creating the inputs and outputs of the drivers
9	Creating the inputs of the stepper motors (2A, 2B, 1A and 1B)
10	Creating the 12V power supply using a DC generator
11	Adding the ground to the board
12	Linking the generator VCC to the drivers
13	Linking the drivers to the stepper motors using the input and output pins

The circuit realized in Proteus is given in Figure 13:

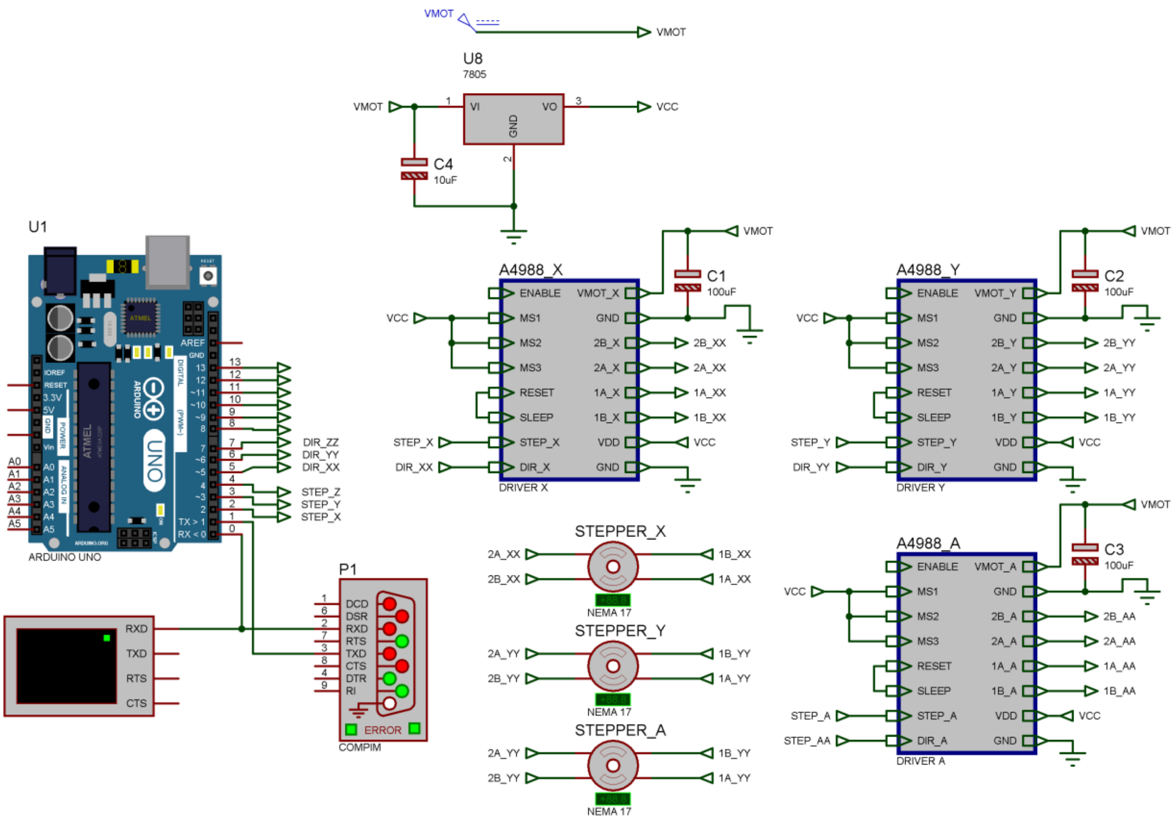


Figure 13: Electronic circuit by Proteus 8

After the establishment of the electronic circuit, we needed to link our circuit to a GRBL controller; we decided to use the same software used for our machine, which is LaserGRBL; the steps of the program implementation are given in Table 18:

Table 18: Program implementation steps

Steps	Operation
1	Creating virtual serial port COM4 using VSPE software, to link the Arduino board to the Arduino IDE and the GRBL controller
2	Opening the ino file (grblUpload) in the Arduino IDE
3	Compiling the grblUpload example in the Arduino IDE
4	Coping the tree structure of the file resulting from the compilation
5	Linking the compiled file tree structure to the Arduino board
6	Opening the LaserGRBL software
7	Selecting the virtual serial port created before in the LaserGRBL
8	Opening a new file in LaserGRBL
9	Starting the Proteus simulation
10	Starting the G-code generation and execution in LaserGRBL

When starting the execution of the G-code generated in LaserGRBL, we can see the movement of the stepper motors and their instant position, as shown in Figure 14:

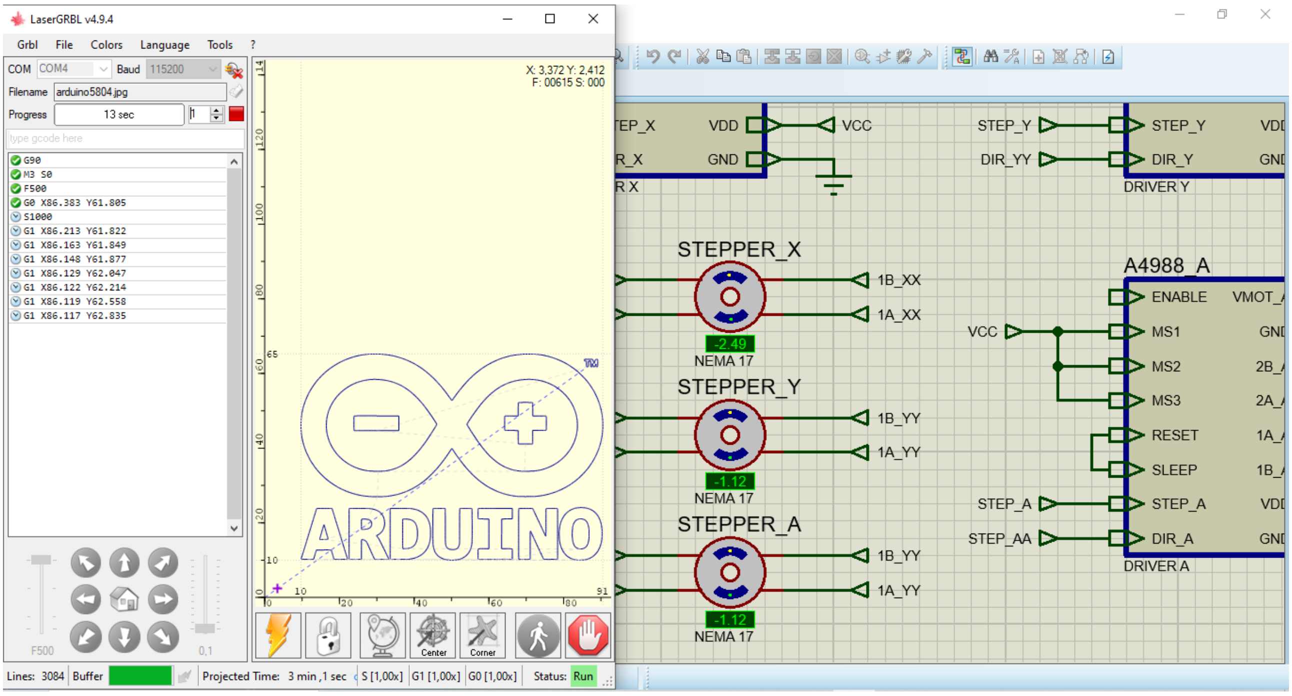


Figure 14: Electronic circuit simulation by Proteus 8

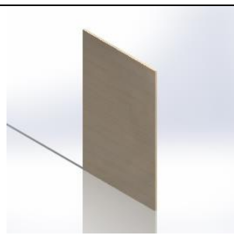
IV.3 Mechanical Subsystem

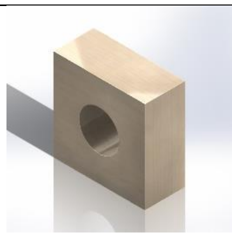
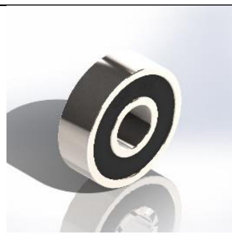
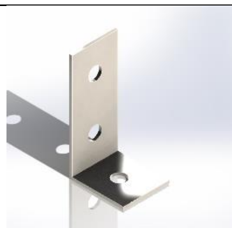
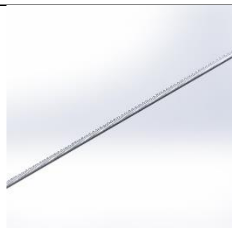
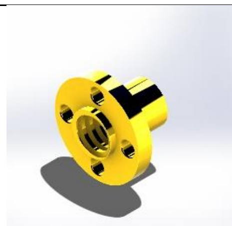
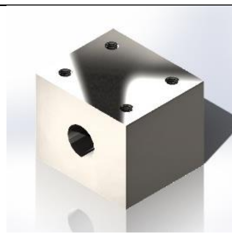
SolidWorks 2019 do the design of the mechanical subsystem of our machine; the assembly file has 76 components from 26 parts.

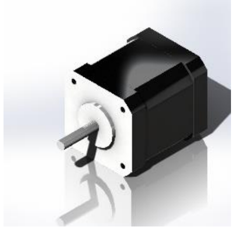
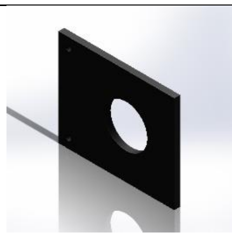
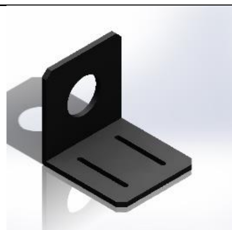
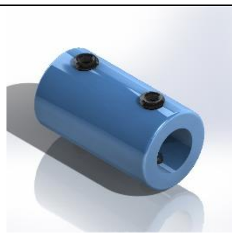
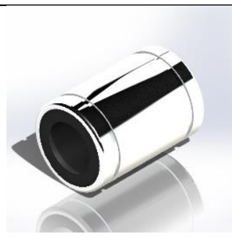
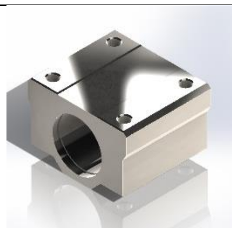
IV.3.1 Mechanical parts design

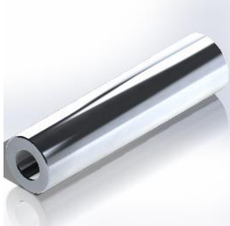
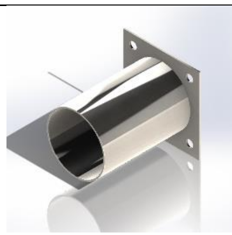
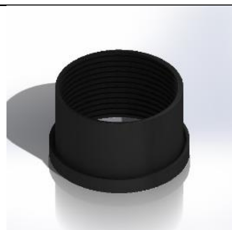
The parts of the machine are given in the Table 19:

Table 19: Machine mechanical parts

Name	Quantity	Materiel	Image
Table	1	Melamine	
Left support of the bridge	1	Melamine	
Right support of the bridge	1	Melamine	

Bridge	1	Melamine	
Ball bearing bracket	2	Wood	
Ball bearing	3	Steel Carbon Chrome Ceramic Polymer	
Shaft	4	Steel	
Ball bearing bracket fixing	4	Aluminum	
Leadscrew	3	Steel	
Leadscrew Nut	3	Brass	
Leadscrew Nut Housing	3	Aluminum	

ITC-CNC-3 stepper motor	3		
Flat stepper motor mount	1	Aluminum	
Bent stepper motor mount	2	Aluminum	
Shaft coupler	3	Aluminum	
Ball bearing	4	Steel Carbon Chrome Ceramic Polymer	
SCS12UU	4	Aluminum	
SK12	4	Aluminum	
Laser head adjustable module mounting frame	1	Steel Aluminum	

Spacer	4	Aluminum	
Table leg	4	Aluminum	
	4	Polymer	
	4	Polymer	

IV.3.2 Mechanical assembly design

The 6 views of the assembly, top view, bottom view, left view, right view, front view, rear view, and the isometric view are given in Figures 15-21:

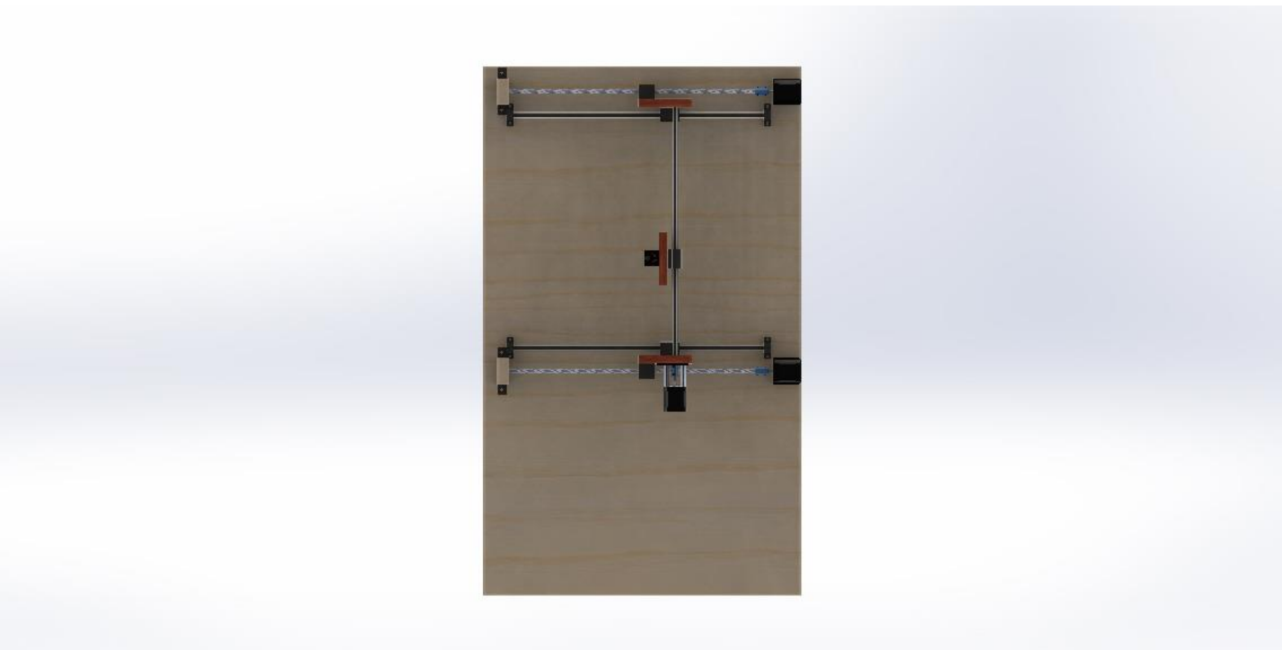


Figure 15: Top view

Figure 16: Bottom view

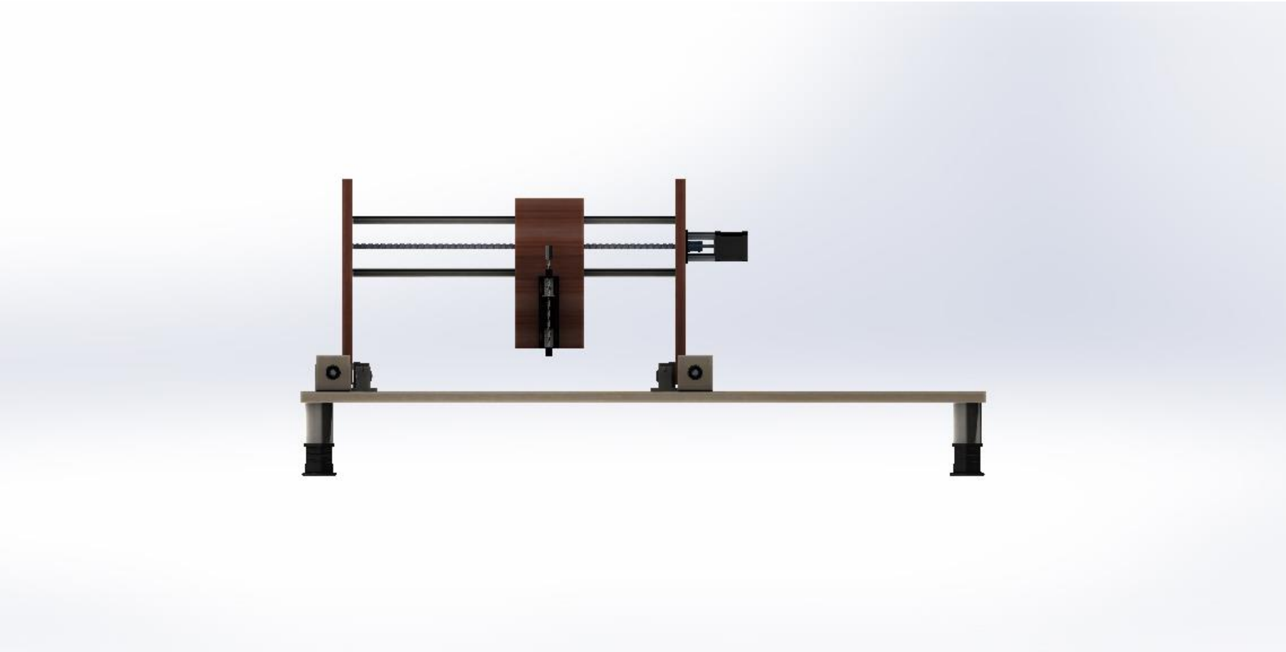


Figure 17: Front view

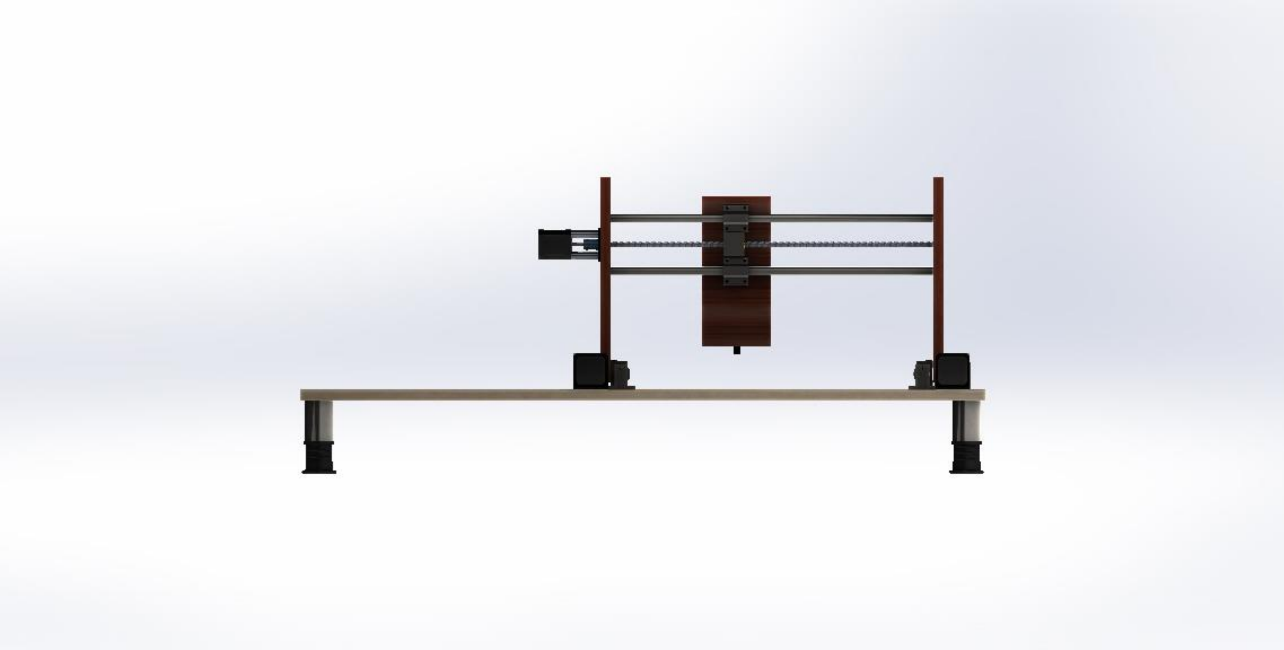


Figure 18: Rear view

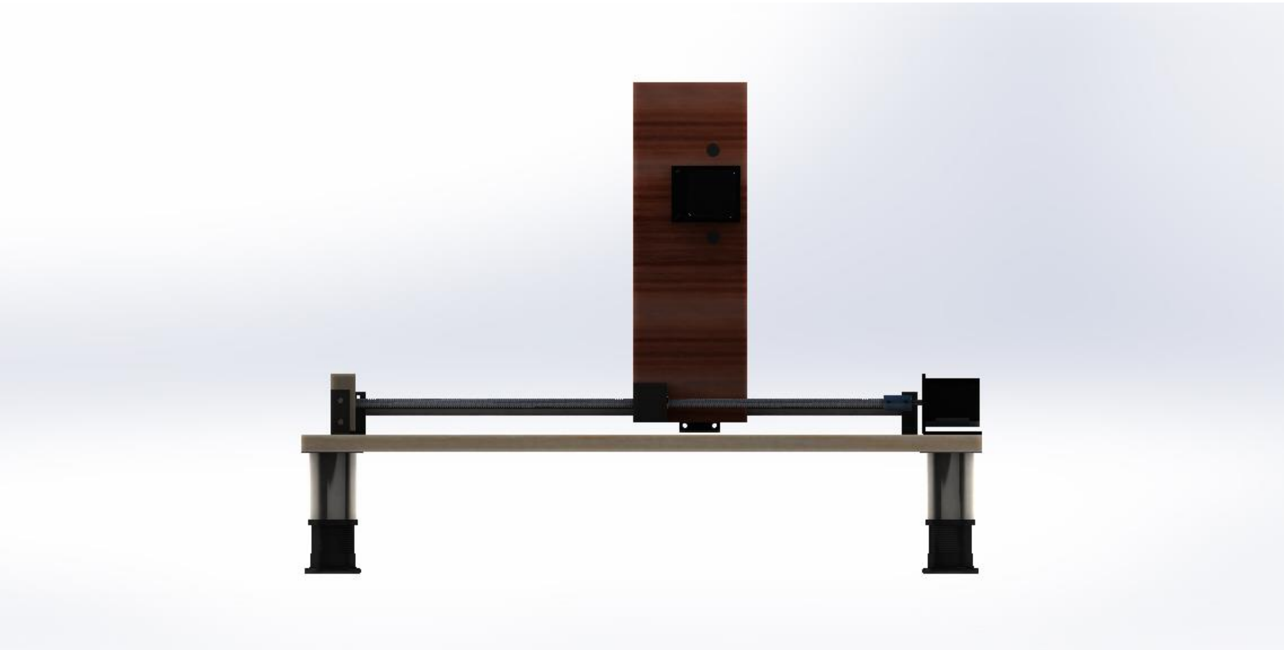


Figure 19: Right view

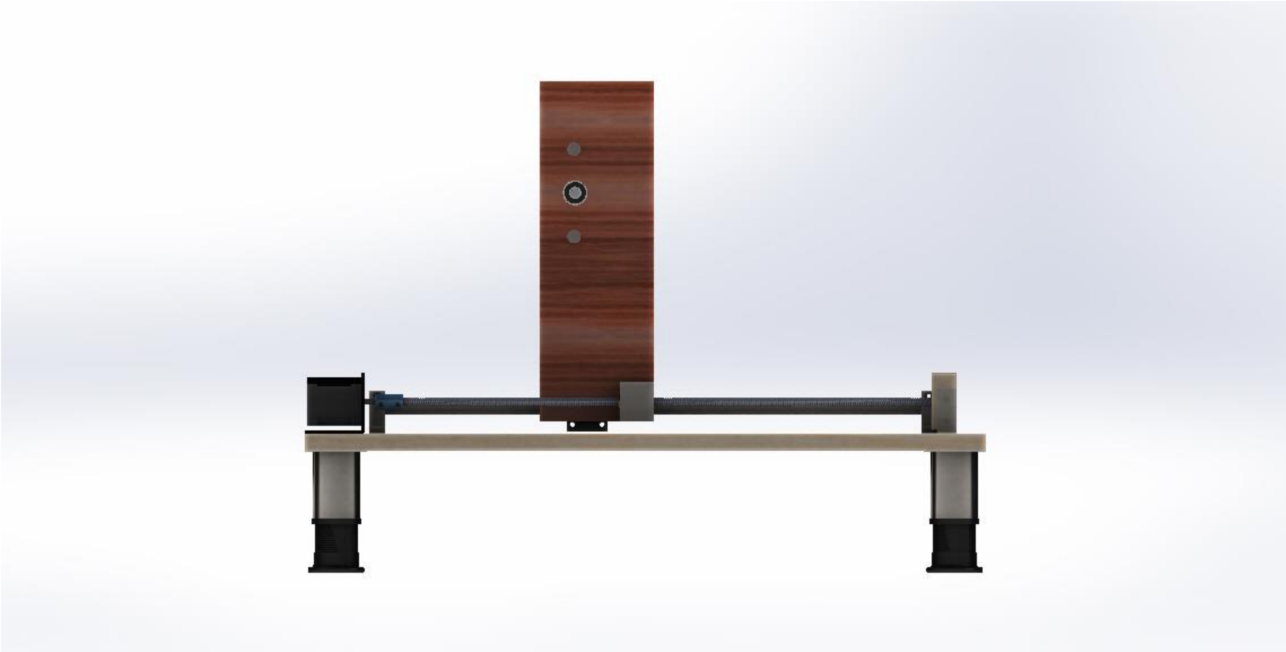


Figure 20: Left view

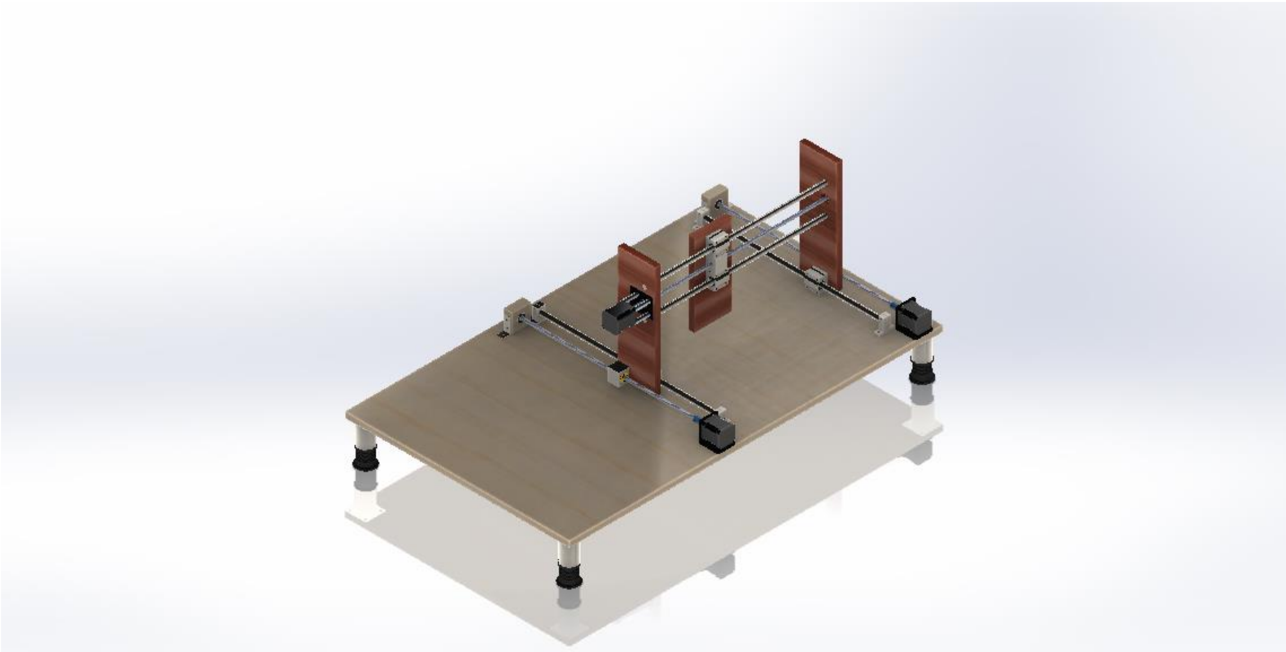


Figure 21: Isometric view

IV.3.3 Movement mechanisms

The study of the nature of the relationship between the elements of our machine is done by carrying out the link graph and kinematic diagram.

IV.3.4 Movement mechanism of the axis Y

All elements of the mechanism of the Y-axis are shown in Figure 22, and they are defined as follows:

- Element (1): Slide unit
- Element (2): Lead screw nut housing bracket
- Element (3): Linear shaft
- Element (4): Gantry
- Element (5): Ball bearing
- Element (6): Stepper motor
- Element (7): Lead screw

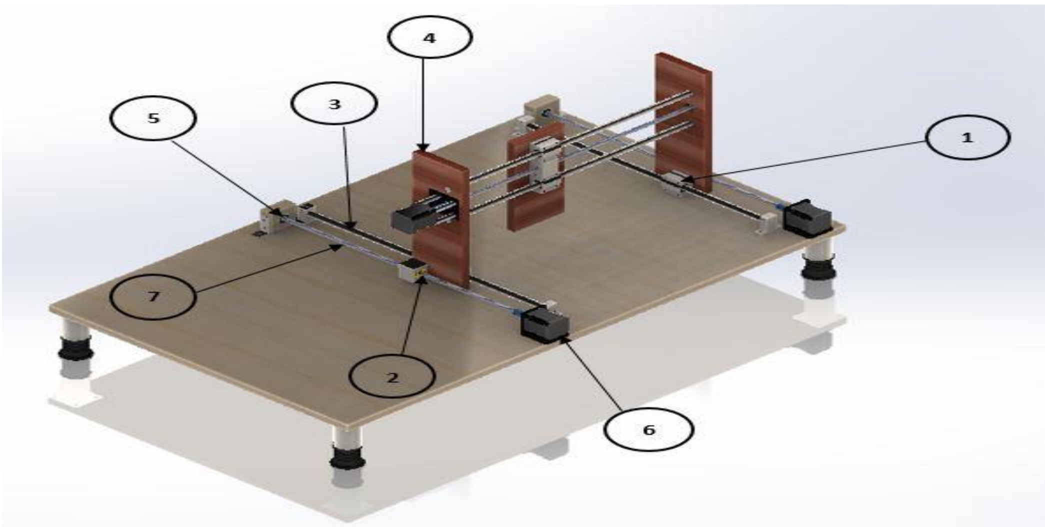


Figure 22: Mechanism of Y axis

The link graph is given in Figure 23, each element is represented by a circle and the link by rectangular.

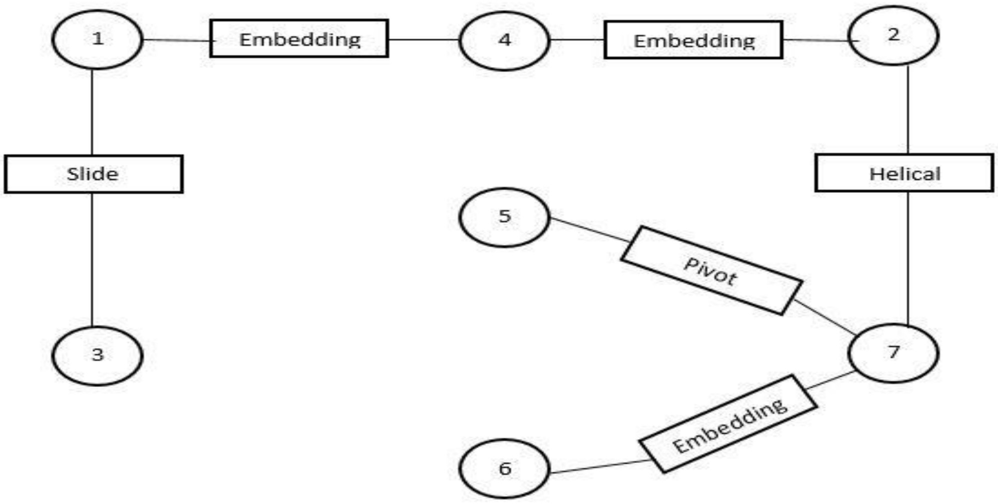


Figure 23: Link graph of the mechanism of Y-axis

IV.3.5 Movement mechanism of the axis X

All elements of the mechanism of the X-axis are shown in Figure 24, and they are defined as follows:

- Element (1): Slide unit
- Element (2): Linear shaft
- Element (3): Stepper motor
- Element (4): Gantry
- Element (5): Ball bearing
- Element (6): Lead screw nut housing bracket
- Element (7): Lead screw

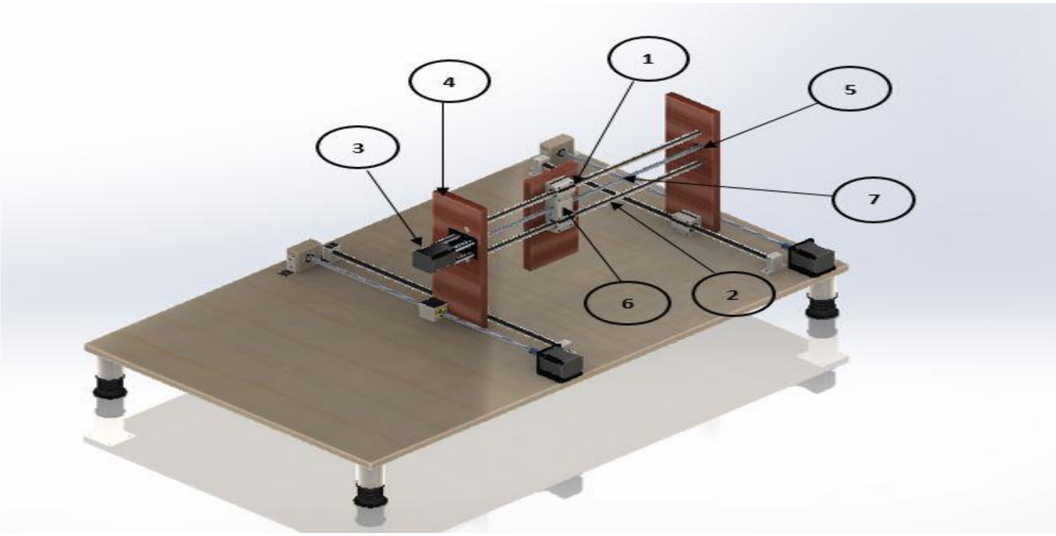


Figure 24: Mechanism of X axis

The link graph is given in Figure 25, each element is represented by a circle and the link by rectangular.

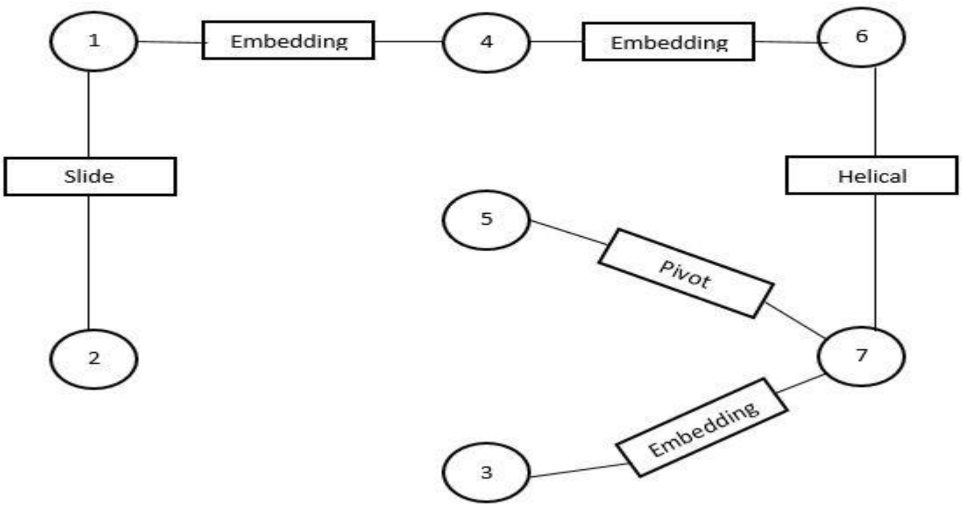


Figure 25: Link graph of the mechanism of X-axis

IV.3.6 Kinematic diagram

The kinematic diagram of our machine is given in Figure 26, it illustrates the connectivity of links rather than the dimension of the parts in our case the cubes represent the stepper motor, the cylinder shapes represent helical and pivot links for parallelepiped form represents slide link and F represents the load.

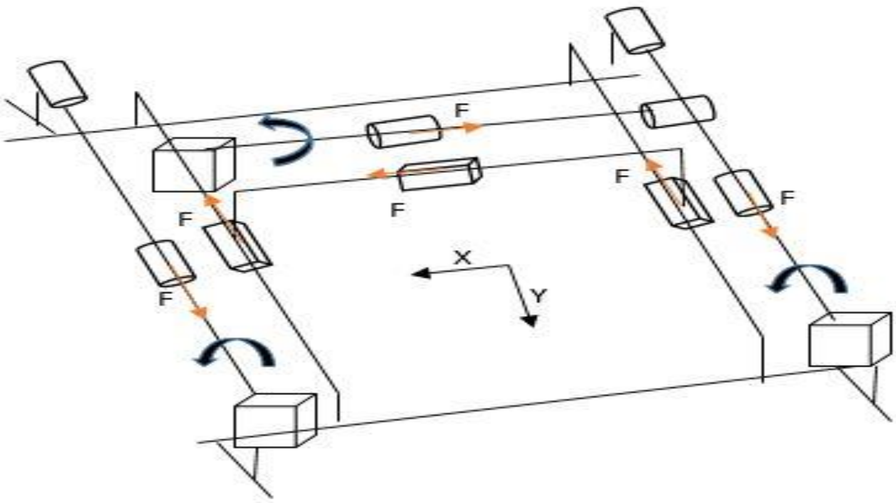
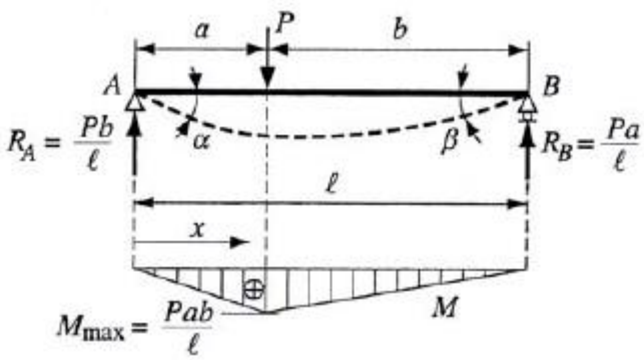


Figure 26: Kinematic diagram

IV.4 Strength of materials calculation

Static calculation makes it possible to carry out calculations of the resistance of materials whose objective is to reduce the study of the overall behavior of a structure (relationship between stresses/forces or moments and displacements) to that of the local behavior of the materials composing it (relationship between stresses and strains).

In our mechanical structure, the only stress that exists is bending. So, in this study we will calculate the maximum deflection of the straight beams which are the guide rods which aim to support the weights of the parts suspended in each axis.



The calculation of the maximum deflection is done by this elastic line relationship:

$$y = \frac{P}{6lEI}(2ab^2x + a^2bx - bx^3) \qquad (0 \leq x \leq a)$$

$$y = \frac{P}{6lEI}[2a^2b(l-x) + ab^2(l-x) - a(l-x)^3] \qquad (a \leq x \leq l)$$

With:

P: Force applied

l : Beam length

E : Young's modulus

I : Moment of inertia of a circle of diameter D

x : Force application position

In each point of force application, the straight beam which is the guide rod in our machine, the rod is going to have a maximum deflection.

In the next part we will choose the point of application of the force "x" in the middle of the beam to have the largest maximum deflection at the same point. Because the position of the deflection is given by the following relation.

$$\sqrt{\frac{1}{3}+\frac{2b}{3a}} \quad if \quad a > b \qquad or \qquad l-b\sqrt{\frac{1}{3}+\frac{2a}{3b}} \quad if \quad a < b$$

For the X axis:

P (N) = 7.5

l (mm) = 500

E (Gpa) = 210

I (mm^4) = $\frac{\pi D^4}{64}$ =1017

x (mm) = a (mm) = 25

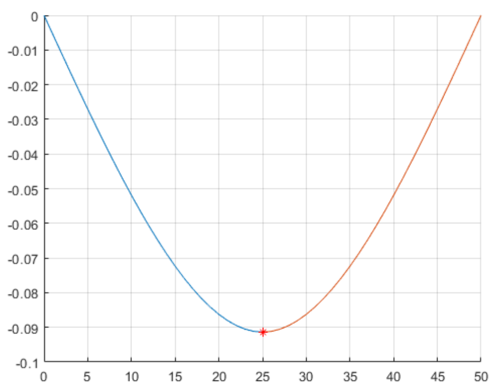


Figure 27: X axis deflection

The maximum deflection is equal to $0.09 * 10^{-6}m$, according to this Matlab graph, shown in figure 27.

For the Y axis:

P (N) = 20

l (mm) = 500

E (Gpa) = 210

I (mm^4) = $\frac{\pi D^4}{64}$ = 1017

x (mm) = a (mm) = 25

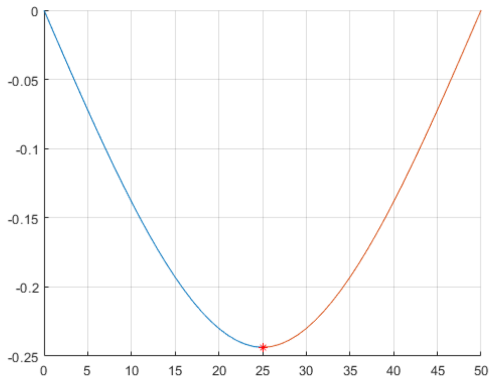


Figure 28: Y axis deflection

The maximum deflection is equal to $0.25 * 10^{-6}m$, as shown in figure 28, we notice that the maximum deflection in the guide rods due to the weight exerted on them is infinitely low and negligible compared to the length of the rods, therefore it does not represent any problem during the operation of the machine.

IV.5 Conclusion

Through this chapter, we have presented the technical specifications of all electronic devices followed by their circuit design by Fritzing and Proteus 8 with the simulation; we also presented all designed mechanical parts, their assembly, and some useful diagrams.

CHAPTER V

Realization of the machine

V.1 Introduction

After establishing the mechanical structure design and the electronic circuit design, we will present in this chapter the realization phase of the machine, starting with the assembly steps and finishing with some engraved drawings realized with our machine.

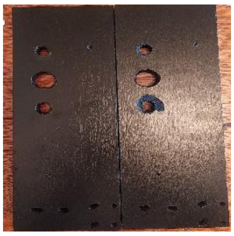
V.2 Machine assembly steps

As mentioned, our machine is divided into four subsystems: mechanical, electronics, and software. We will present in this part the realization done in each subsystem.

V.2.1 Mechanical subsystem realization

In the mechanical subsystem, some parts are made by us, and the rest are bought; all the parts made by us are given in Table 20:

Table 20: Manufactured parts

Name	Quantity	Dimensions	Materiel	Image
Table	1	Length: 1000 mm Width: 600 mm Thickness: 15 mm	Melamine	
Left support of the bridge	1	Length: 300 mm Width: 100 mm Thickness: 15 mm	Melamine	
Right support of the bridge	1	Length: 300 mm Width: 100 mm Thickness: 15 mm	Melamine	
Bridge	1	Length: 220 mm Width: 100 mm Thickness: 15 mm	Melamine	
Ball bearing bracket	2	Length: 50 mm Width: 50 mm Thickness: 20 mm	Wood	
Shaft	4	Length: 500 mm Diameter: 12 mm	Steel	

After fixing all the mechanical parts, the result is given in Figure 29:

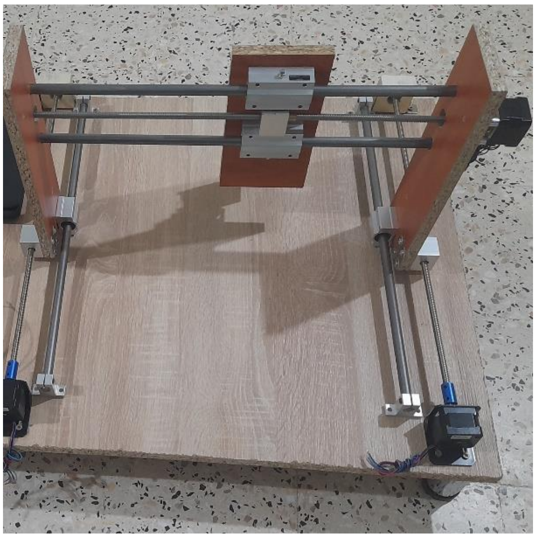
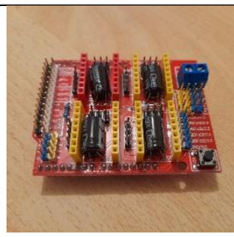
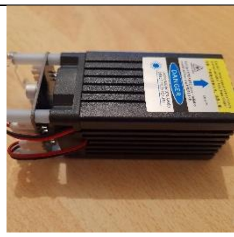


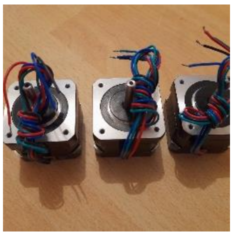
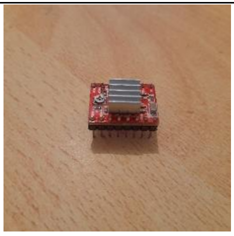
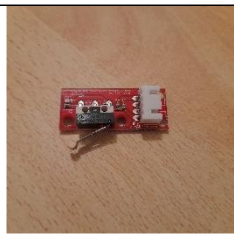
Figure 29: Mechanical structure

V.2.2 Electronic subsystem

In the electronic subsystem, all devices are grouped and connected to the Arduino board, as shown in the electrical diagram in the previous chapter; all the equipment and instruments are given in Table 21:

Table 21: Electronic components

Name	Quantity	Image
Arduino UNO board	1	
CNC shield V3	1	
Laser module	1	

Stepper motor	3	
Stepper motor driver	3	
Limit switch	4	
Power supply 12V 5A	1	
Power supply 12V 2A	1	
Emergency stop	1	

After connecting all the equipment, the result is given in Figure 30:

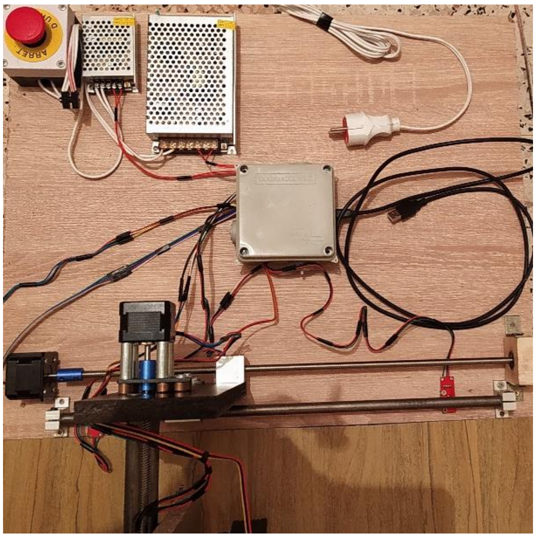


Figure 30: Electronic circuit

V.2.3 Software subsystem

In the previous chapter, we presented the three software used by the machine, and in this part, we will show how to link all these software to make the machine work correctly.

Arduino IDE setting up steps: All the steps are given in Table 22:

Table 22: Arduino IDE setting up steps

Step	Operation
1	Selecting the port in which the Arduino board is connected
2	Selecting the type of the Arduino board (UNO)
3	Downloading the Grbl firmware file (grbl 1.1h.20190825)
4	Including the firmware file as a library in Arduino IDE
5	Opening the inner file (grblUpload) in the IDE
6	Uploading the code to the Arduino board

This setup is done only once; the machine will operate only with the LaserGRBL software.

LaserGRBL setting up steps: All the steps are given in Table 23:

Table 23: LaserGRBL setting up steps

Step	Operation
1	Selecting the port in which the Arduino board is connected
2	Connecting the software to the board
3	Configuring the Grbl by defining the values of the parameters (done only one time)
4	Opening a file in a supported format
5	Selecting the parameters of the drawing (Resize, Grayscale, Brightness, Contrast and White Clip)

6	Selecting the Conversion Tool (Line to Line Tracing, 1bit BW Dithering, Vectorize, Centerline and Passthrough)
7	Selecting the Tool options
8	Selecting the engraving speed
9	Selecting the laser options (Laser Mode, S-MIN and S-MAX)
10	Selecting the image size and position (Size and offset)
11	Moving the laser module to an initial point
12	Homing the machine
13	Clicking start

V.3 Tests and results

After assembling the mechanical structure and electronic circuit, here is an image of the machine shown in Figure 31:

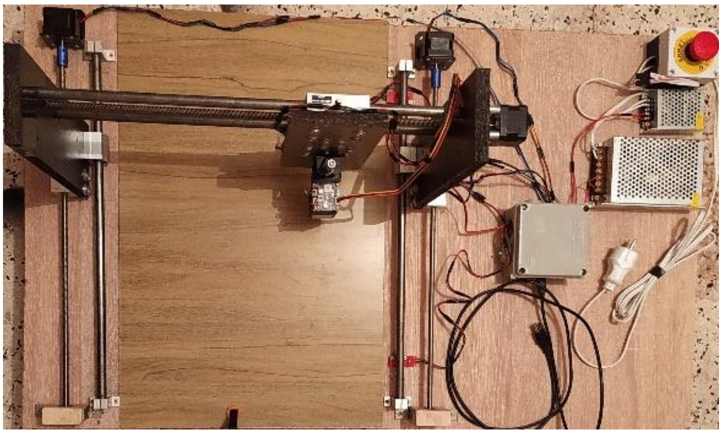


Figure 31: Machine

Here is the Arduino logo engraved in two different materials, Aluminum and Melamine given in Figure 32 and 33:

Figure 32: Arduino logo engraved in Aluminum

Figure 33: Arduino logo engraved in Melamine

V.4 Conclusion

Through this last chapter, we have presented the mechanical parts made by us, followed by the assembled mechanical structure; we also introduced the electronic devices used in our machine, followed by the electronic circuit, and finally, all the machines in one piece.

Conclusion

Our final year project involves the design, control, and realization of a CNC laser-engraving machine based on Arduino UNO board and laserGRBL software, which works in conjunction with GRBL firmware to control the laser module.

First, we presented an overview of CNC machining by giving the history of CNC machines, and then cited the main components of computer numerical control, types, and classification. We subsequently reviewed laser CNC machines, their types, advantages, and disadvantages.

Then, before directly realizing our machine, we presented a functional analysis, which is an important step in choosing our technological solutions. After that, we designed our machine using SolidWorks 2019, and we presented all the electronic and electrical components. Next, we mention the three essential software used to control the laser machine: Arduino IDE, GRBL firmware, and laserGRBL. The last part is devoted to the realization of the CNC laser-engraving machine, in which we have presented the machine and its electronic circuit and mechanical structure and also some of the engraved plates done with the machine.

As a future perspective, we propose using wireless Bluetooth communication via an Android application. We will also work on reducing the vibration during the operating time. As well as we will develop a geometric error model of our machine using the multi-body system theory in order to assess the significant error items that have the greatest impact on precision.

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Appendix A: Power supply datasheet

TOTAL POWER INT'L

60W Single Output Switching Power Supply **S-60 series**

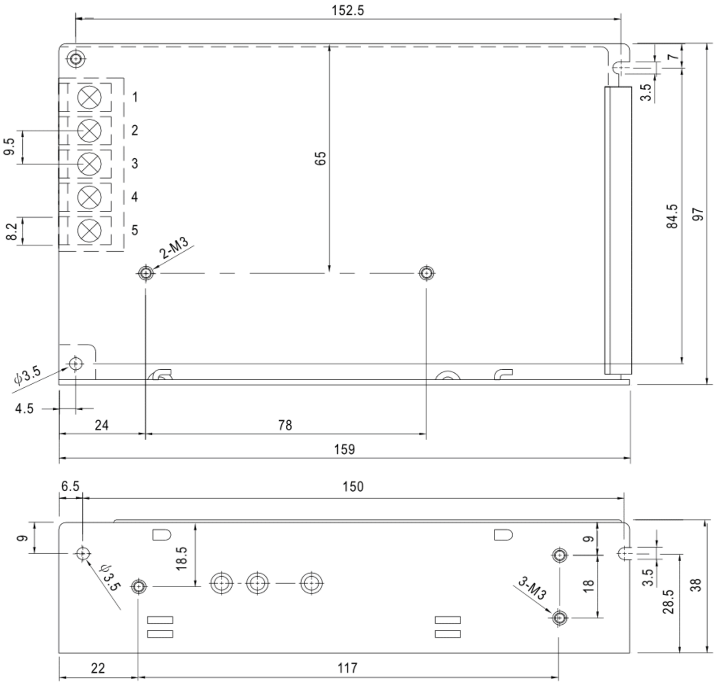
■ Features :
- Universal AC input/Full range
- Protections:Short circuit/Over load/Over voltage
- Cooling by free air convection
- 100% full load burn-in test
- Fixed switching frequency at 50KHz
- 2 years warranty

SPECIFICATION

MODEL		S-60-5	S-60-12	S-60-15	S-60-24
OUTPUT	DC VOLTAGE	5V	12V	15V	24V
	RATED CURRENT	12A	5A	4A	2.5A
	CURRENT RANGE	0 ~ 12A	0 ~ 5A	0 ~ 4A	0 ~ 2.5A
	RATED POWER	60W	60W	60W	60W
	RIPPLE & NOISE (max.) Note.2	120mVp-p	120mVp-p	150mVp-p	150mVp-p
	VOLTAGE ADJ. RANGE	4.75 ~ 5.5V	10.8 ~ 13.2V	13.5 ~ 16.5V	21.6 ~ 26.4V
	VOLTAGE TOLERANCE Note.3	±2.0%	±1.0%	±1.0%	±1.0%
	LINE REGULATION	±0.5%	±0.5%	±0.5%	±0.5%
	LOAD REGULATION	±1.0%	±0.5%	±0.5%	±0.5%
	SETUP, RISE, HOLD TIME	300ms, 50ms, 80ms / 230VAC 800ms, 50ms, 10ms / 115VAC at full load			
INPUT	VOLTAGE RANGE	85 ~ 264VAC 120 ~ 370VDC			
	FREQUENCY RANGE	47 ~ 63Hz			
	EFFICIENCY(Typ.)	73%	76%	77%	79%
	AC CURRENT	2A/115VAC 1A/230VAC			
	INRUSH CURRENT(max.)	COLD START 30A/115VAC 60A/230VAC			
	LEAKAGE CURRENT	<3.5mA / 240VAC			
PROTECTION	OVER LOAD	105 ~ 150% rated output power			
		Protection type : Hiccup mode, recovers automatically after fault condition is removed.			
	OVER VOLTAGE	5.75 ~ 6.75V	13.8 ~ 16.2V	17.25 ~ 20.25	27.6 ~ 32.4V
		Protection type : Hiccup mode, recovers automatically after fault condition is removed.			
ENVIRONMENT	WORKING TEMP.	-10 ~ +60℃ (Refer to output load derating curve)			
	WORKING HUMIDITY	20 ~ 90% RH non-condensing			
	STORAGE TEMP., HUMIDITY	-20 ~ +85℃, 10 ~ 95% RH			
	TEMP. COEFFICIENT	±0.03%/℃ (0 ~ 50℃)			
	VIBRATION	10 ~ 500Hz, 2G 10min./1cycle, period for 60min. each along X, Y, Z axes			
SAFETY & EMC (Note 4)	SAFETY STANDARDS	UL1012, UL1950, TUV EN60950 Approved			
	WITHSTAND VOLTAGE	I/P-O/P:3KVAC I/P-FG:1.5KVAC O/P-FG:0.5KVAC			
	ISOLATION RESISTANCE	I/P-O/P, I/P-FG, O/P-FG:100M Ohms/500VDC			
	EMI CONDUCTION & RADIATION	Compliance to EN55022 (CISPR22) Class B			
	HARMONIC CURRENT	Compliance to EN61000-3-2,-3			
	EMS IMMUNITY	Compliance to EN61000-4-2,3,4,5,6,8,11; ENV50204, EN55024, Light industry level, criteria A			
OTHERS	MTBF	316.2K hrs min. MIL-HDBK-217F (25℃)			
	DIMENSION	159*97*38mm (L*W*H)			
	PACKING	0.51Kg; 24pcs/13.1Kg/0.7CUFT			
NOTE	1. All parameters NOT specially mentioned are measured at 230VAC input, rated load and 25℃ of ambient temperature. 2. Ripple & noise are measured at 20MHz of bandwidth by using a 12" twisted pair-wire terminated with a 0.1uf & 47uf parallel capacitor. 3. Tolerance : includes set up tolerance, line regulation and load regulation. 4. The power supply is considered a component which will be installed into a final equipment. The final equipment must be re-confirmed that it still meets EMC directives.				

■ Mechanical Specification

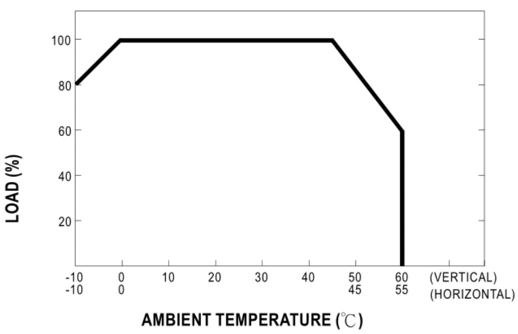
Case No. 901 Unit:mm



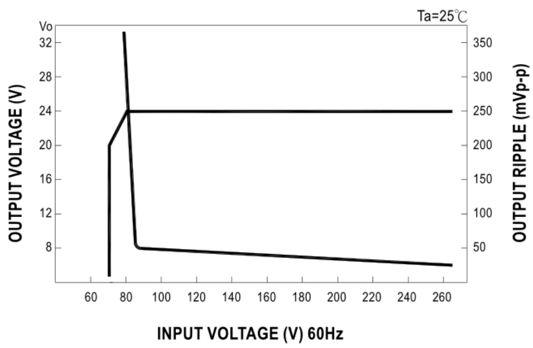
Terminal Pin. No Assignment

Pin No.	Assignment	Pin No.	Assignment
1	AC/L	4	DC OUTPUT -V
2	AC/N	5	DC OUTPUT +V
3	FG ⏚		

■ Output Derating

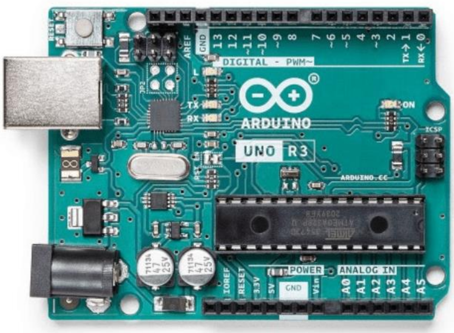


■ Static Characteristics (24V)



Appendix B: Arduino UNO R3 datasheet

Product Reference Manual
SKU: A000066



Description

The Arduino UNO R3 is the perfect board to get familiar with electronics and coding. This versatile microcontroller is equipped with the well-known ATmega328P and the ATMega 16U2 Processor.
This board will give you a great first experience within the world of Arduino.

Target areas:

Maker, introduction, industries

Features

- **ATMega328P** Processor
  - **Memory**
    - AVR CPU at up to 16 MHz
    - 32KB Flash
    - 2KB SRAM
    - 1KB EEPROM
  - **Security**
    - Power On Reset (POR)
    - Brown Out Detection (BOD)
  - **Peripherals**
    - 2x 8-bit Timer/Counter with a dedicated period register and compare channels
    - 1x 16-bit Timer/Counter with a dedicated period register, input capture and compare channels
    - 1x USART with fractional baud rate generator and start-of-frame detection
    - 1x controller/peripheral Serial Peripheral Interface (SPI)
    - 1x Dual mode controller/peripheral I2C
    - 1x Analog Comparator (AC) with a scalable reference input
    - Watchdog Timer with separate on-chip oscillator
    - Six PWM channels
    - Interrupt and wake-up on pin change
  - **ATMega16U2 Processor**
    - 8-bit AVR® RISC-based microcontroller
  - **Memory**
    - 16 KB ISP Flash
    - 512B EEPROM
    - 512B SRAM
    - debugWIRE interface for on-chip debugging and programming
  - **Power**
    - 2.7-5.5 volts

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1 The Board

1.1 Application Examples

The UNO board is the flagship product of Arduino. Regardless if you are new to the world of electronics or will use the UNO as a tool for education purposes or industry-related tasks.

First entry to electronics: If this is your first project within coding and electronics, get started with our most used and documented board; Arduino UNO. It is equipped with the well-known ATmega328P processor, 14 digital input/output pins, 6 analog inputs, USB connections, ICSP header and reset button. This board includes everything you will need for a great first experience with Arduino.

Industry-standard development board: Using the Arduino UNO board in industries, there are a range of companies using the UNO board as the brain for their PLC's.

Education purposes: Although the UNO board has been with us for about ten years, it is still widely used for various education purposes and scientific projects. The board's high standard and top quality performance makes it a great resource to capture real time from sensors and to trigger complex laboratory equipment to mention a few examples.

1.2 Related Products

- Starter Kit
- Tinkerkit Braccio Robot
- Example

2 Ratings

2.1 Recommended Operating Conditions

Symbol	Description	Min	Max
	Conservative thermal limits for the whole board:	-40 °C (-40°F)	85 °C (185°F)

NOTE: In extreme temperatures, EEPROM, voltage regulator, and the crystal oscillator, might not work as expected due to the extreme temperature conditions

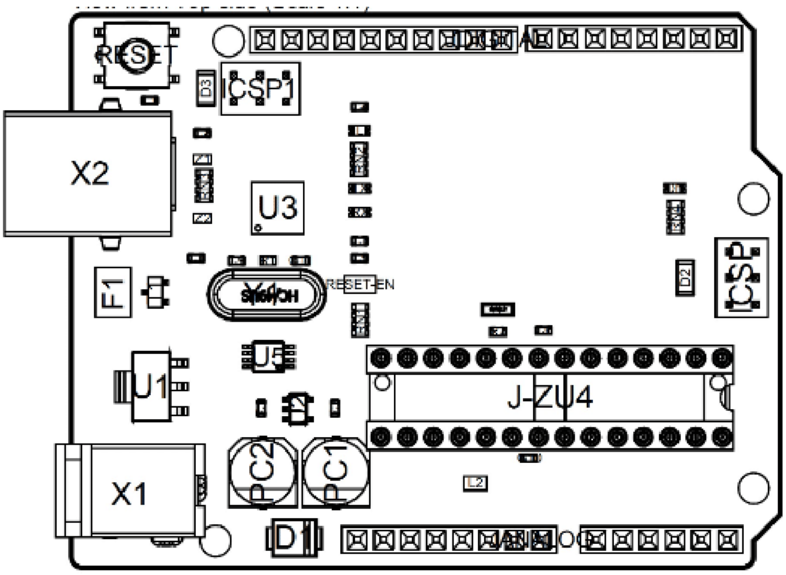
2.2 Power Consumption

Symbol	Description	Min	Typ	Max	Unit
VINMax	Maximum input voltage from VIN pad	6	-	20	V
VUSBMax	Maximum input voltage from USB connector		-	5.5	V
PMax	Maximum Power Consumption	-	-	xx	mA

3 Functional Overview

3.1 Board Topology

Top view



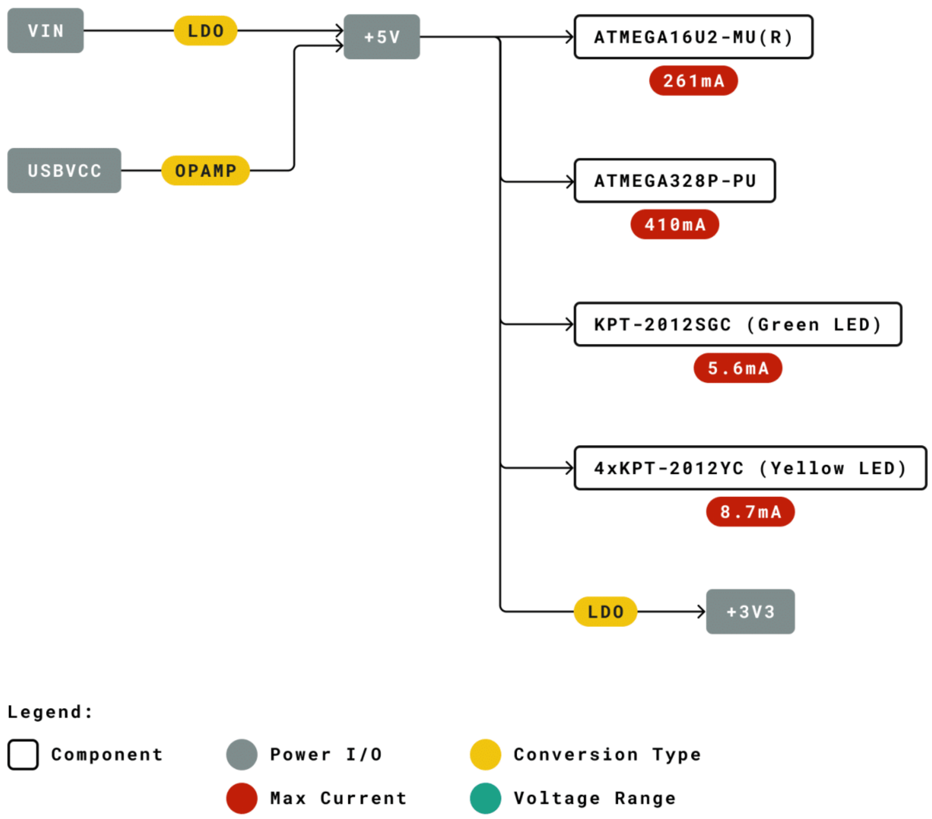
Board topology

Ref.	Description	Ref.	Description
X1	Power jack 2.1x5.5mm	U1	SPX1117M3-L-5 Regulator
X2	USB B Connector	U3	ATMEGA16U2 Module
PC1	EEE-1EA470WP 25V SMD Capacitor	U5	LMV358LIST-A.9 IC
PC2	EEE-1EA470WP 25V SMD Capacitor	F1	Chip Capacitor, High Density
D1	CGRA4007-G Rectifier	ICSP	Pin header connector (through hole 6)
J-ZU4	ATMEGA328P Module	ICSP1	Pin header connector (through hole 6)
Y1	ECS-160-20-4X-DU Oscillator		

3.2 Processor

The Main Processor is a ATmega328P running at up tp 20 MHz. Most of its pins are connected to the external headers, however some are reserved for internal communication with the USB Bridge coprocessor.

3.3 Power Tree



Power tree

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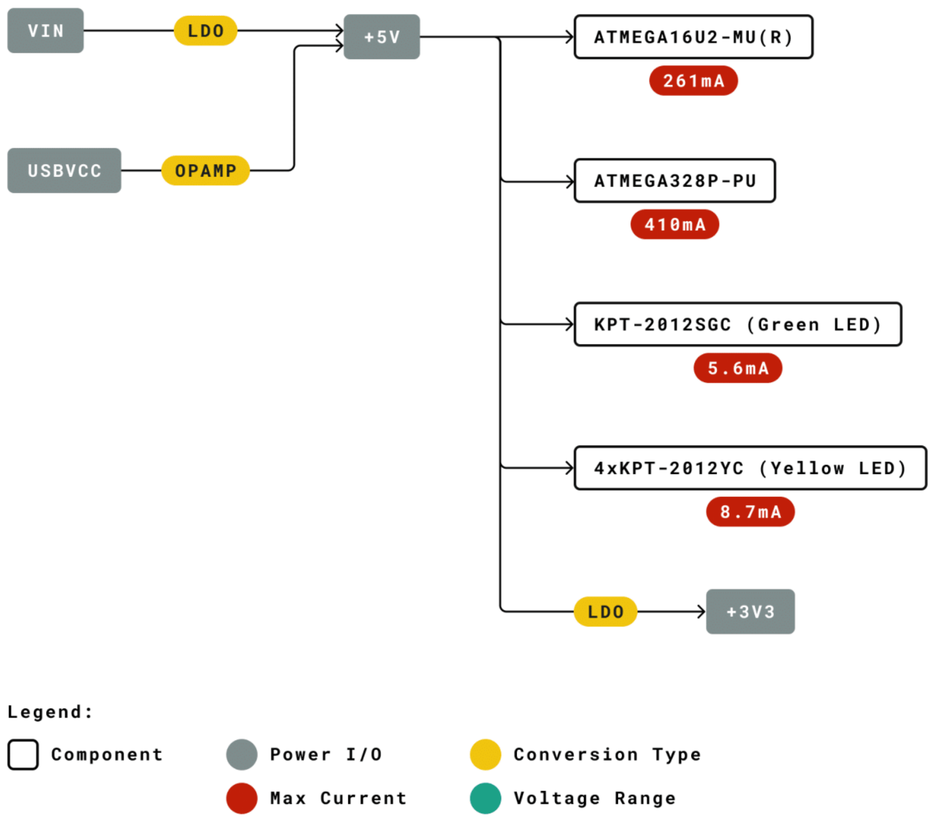


Power tree

4 Board Operation

4.1 Getting Started - IDE

If you want to program your Arduino UNO while offline you need to install the Arduino Desktop IDE [1] To connect the Arduino UNO to your computer, you'll need a Micro-B USB cable. This also provides power to the board, as indicated by the LED.

4.2 Getting Started - Arduino Web Editor

All Arduino boards, including this one, work out-of-the-box on the Arduino Web Editor [2], by just installing a simple plugin.

The Arduino Web Editor is hosted online, therefore it will always be up-to-date with the latest features and support for all boards. Follow **[3]** to start coding on the browser and upload your sketches onto your board.

4.3 Getting Started - Arduino IoT Cloud

All Arduino IoT enabled products are supported on Arduino IoT Cloud which allows you to Log, graph and analyze sensor data, trigger events, and automate your home or business.

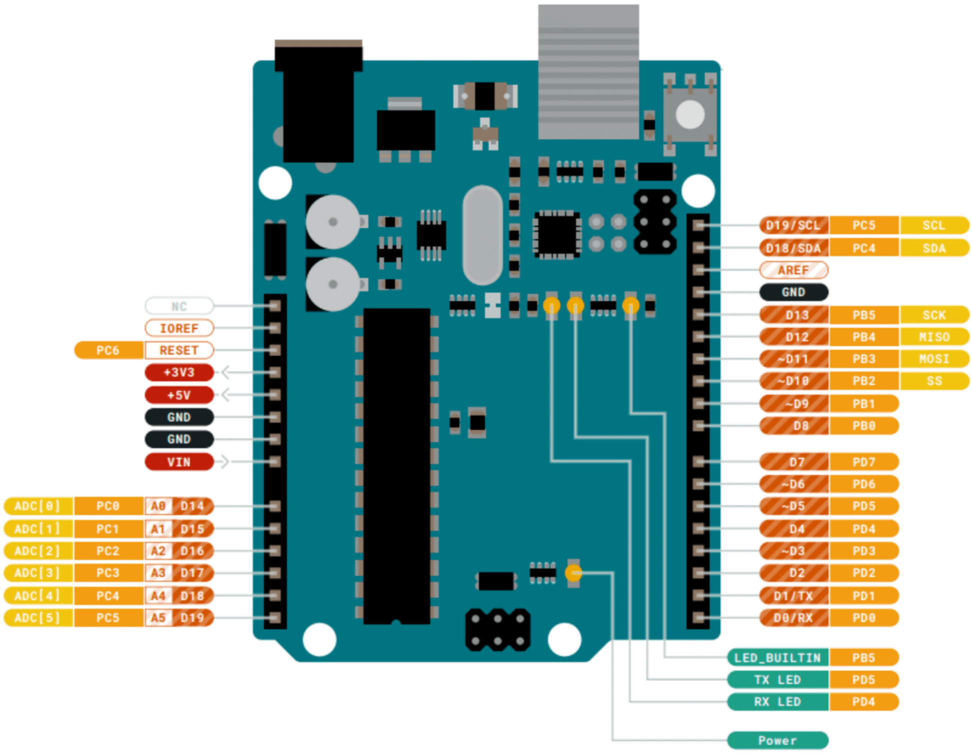
4.4 Sample Sketches

Sample sketches for the Arduino XXX can be found either in the “Examples” menu in the Arduino IDE or in the “Documentation” section of the Arduino Pro website [4]

4.5 Online Resources

Now that you have gone through the basics of what you can do with the board you can explore the endless possibilities it provides by checking exciting projects on ProjectHub **[5]**, the Arduino Library Reference **[6]** and the online store **[7]** where you will be able to complement your board with sensors, actuators and more

5 Connector Pinouts



Pinout

5.1 JANALOG

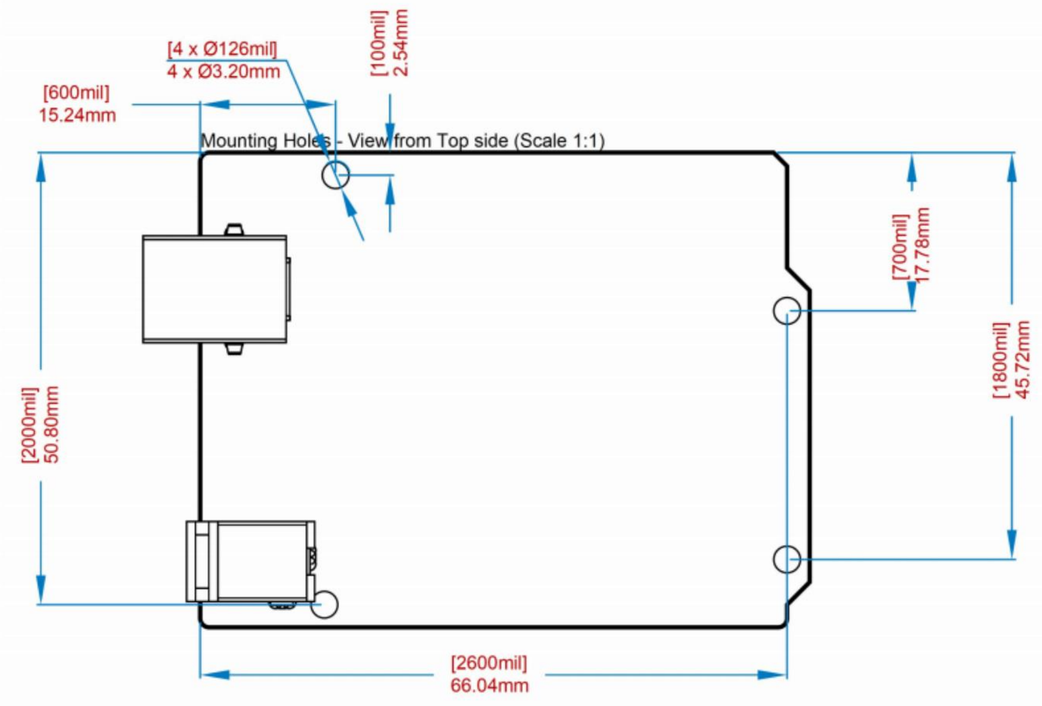
Pin	Function	Type	Description
1	NC	NC	Not connected
2	IOREF	IOREF	Reference for digital logic V - connected to 5V
3	Reset	Reset	Reset
4	+3V3	Power	+3V3 Power Rail
5	+5V	Power	+5V Power Rail
6	GND	Power	Ground
7	GND	Power	Ground
8	VIN	Power	Voltage Input
9	A0	Analog/GPIO	Analog input 0 /GPIO
10	A1	Analog/GPIO	Analog input 1 /GPIO
11	A2	Analog/GPIO	Analog input 2 /GPIO
12	A3	Analog/GPIO	Analog input 3 /GPIO
13	A4/SDA	Analog input/I2C	Analog input 4/I2C Data line
14	A5/SCL	Analog input/I2C	Analog input 5/I2C Clock line

5.2 JDIGITAL

Pin	Function	Type	Description
1	D0	Digital/GPIO	Digital pin 0/GPIO
2	D1	Digital/GPIO	Digital pin 1/GPIO
3	D2	Digital/GPIO	Digital pin 2/GPIO
4	D3	Digital/GPIO	Digital pin 3/GPIO
5	D4	Digital/GPIO	Digital pin 4/GPIO
6	D5	Digital/GPIO	Digital pin 5/GPIO
7	D6	Digital/GPIO	Digital pin 6/GPIO
8	D7	Digital/GPIO	Digital pin 7/GPIO
9	D8	Digital/GPIO	Digital pin 8/GPIO
10	D9	Digital/GPIO	Digital pin 9/GPIO
11	SS	Digital	SPI Chip Select
12	MOSI	Digital	SPI1 Main Out Secondary In
13	MISO	Digital	SPI Main In Secondary Out
14	SCK	Digital	SPI serial clock output
15	GND	Power	Ground
16	AREF	Digital	Analog reference voltage
17	A4/SD4	Digital	Analog input 4/I2C Data line (duplicated)
18	A5/SD5	Digital	Analog input 5/I2C Clock line (duplicated)

5.3 Mechanical Information

5.4 Board Outline & Mounting Holes



Board outline

6 Certifications

6.1 Declaration of Conformity CE DoC (EU)

We declare under our sole responsibility that the products above are in conformity with the essential requirements of the following EU Directives and therefore qualify for free movement within markets comprising the European Union (EU) and European Economic Area (EEA).

ROHS 2 Directive 2011/65/EU	
Conforms to:	EN50581:2012
Directive 2014/35/EU. (LVD)	
Conforms to:	EN 60950-1:2006/A11:2009/A1:2010/A12:2011/AC:2011
Directive 2004/40/EC & 2008/46/EC & 2013/35/EU, EMF	
Conforms to:	EN 62311:2008

6.2 Declaration of Conformity to EU RoHS & REACH 211 01/19/2021

Arduino boards are in compliance with RoHS 2 Directive 2011/65/EU of the European Parliament and RoHS 3 Directive 2015/863/EU of the Council of 4 June 2015 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Substance	Maximum limit (ppm)
Lead (Pb)	1000
Cadmium (Cd)	100
Mercury (Hg)	1000
Hexavalent Chromium (Cr6+)	1000
Poly Brominated Biphenyls (PBB)	1000
Poly Brominated Diphenyl ethers (PBDE)	1000
Bis(2-Ethylhexyl} phthalate (DEHP)	1000
Benzyl butyl phthalate (BBP)	1000
Dibutyl phthalate (DBP)	1000
Diisobutyl phthalate (DIBP)	1000

Exemptions: No exemptions are claimed.

Arduino Boards are fully compliant with the related requirements of European Union Regulation (EC) 1907 /2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). We declare none of the SVHCs (https://echa.europa.eu/web/guest/candidate-list-table), the Candidate List of Substances of Very High Concern for authorization currently released by ECHA, is present in all products (and also package) in quantities totaling in a concentration equal or above 0.1%. To the best of our knowledge, we also declare that our products do not contain any of the substances listed on the "Authorization List" (Annex XIV of the REACH regulations) and Substances of Very High Concern (SVHC) in any significant amounts as specified by the Annex XVII of Candidate list published by ECHA (European Chemical Agency) 1907 /2006/EC.

6.3 Conflict Minerals Declaration

As a global supplier of electronic and electrical components, Arduino is aware of our obligations with regards to laws and regulations regarding Conflict Minerals, specifically the Dodd-Frank Wall Street Reform and Consumer Protection Act, Section 1502. Arduino does not directly source or process conflict minerals such as Tin, Tantalum, Tungsten, or Gold. Conflict minerals are contained in our products in the form of solder, or as a component in metal alloys. As part of our reasonable due diligence Arduino has contacted component suppliers within our supply chain to verify their continued compliance with the regulations. Based on the information received thus far we declare that our products contain Conflict Minerals sourced from conflict-free areas.

7 FCC Caution

Any Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

(1) This device may not cause harmful interference

(2) this device must accept any interference received, including interference that may cause undesired operation.

FCC RF Radiation Exposure Statement:

1. This Transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.
2. This equipment complies with RF radiation exposure limits set forth for an uncontrolled environment.
3. This equipment should be installed and operated with minimum distance 20cm between the radiator & your body.

English: User manuals for license-exempt radio apparatus shall contain the following or equivalent notice in a conspicuous location in the user manual or alternatively on the device or both. This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions:

(1) this device may not cause interference

(2) this device must accept any interference, including interference that may cause undesired operation of the device.

French: Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes :

(1) l' appareil nedoit pas produire de brouillage

(2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

IC SAR Warning:

English This equipment should be installed and operated with minimum distance 20 cm between the radiator and your body.

French: Lors de l' installation et de l' exploitation de ce dispositif, la distance entre le radiateur et le corps est d 'au moins 20 cm.

Important: The operating temperature of the EUT can't exceed 85℃ and shouldn't be lower than -40℃.

Hereby, Arduino S.r.l. declares that this product is in compliance with essential requirements and other relevant provisions of Directive 2014/53/EU. This product is allowed to be used in all EU member states.

8 Company Information

Company name	Arduino S.r.l
Company Address	Via Andrea Appiani 25 20900 MONZA Italy

9 Reference Documentation

Reference	Link
Arduino IDE (Desktop)	https://www.arduino.cc/en/Main/Software
Arduino IDE (Cloud)	https://create.arduino.cc/editor
Cloud IDE Getting Started	https://create.arduino.cc/projecthub/Arduino_Genuino/getting-started-with-arduino-web-editor-4b3e4a
Arduino Pro Website	https://www.arduino.cc/pro
Project Hub	https://create.arduino.cc/projecthub?by=part&part_id=11332&sort=trending
Library Reference	https://www.arduino.cc/reference/en/
Online Store	https://store.arduino.cc/

10 Revision History

Date	Revision	Changes
xx/06/2021	1	Datasheet release

Appendix C: A4988 datasheet

A4988

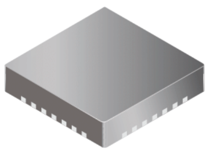
DMOS Microstepping Driver with Translator and Overcurrent Protection

Features and Benefits

- Low $R_{DS(ON)}$ outputs
- Automatic current decay mode detection/selection
- Mixed and Slow current decay modes
- Synchronous rectification for low power dissipation
- Internal UVLO
- Crossover-current protection
- 3.3 and 5 V compatible logic supply
- Thermal shutdown circuitry
- Short-to-ground protection
- Shorted load protection
- Five selectable step modes: full, $^1/_2$, $^1/_4$, $^1/_8$, and $^1/_{16}$

Package:

28-contact QFN
with exposed thermal pad
5 mm × 5 mm × 0.90 mm
(ET package)



Approximate size

Description

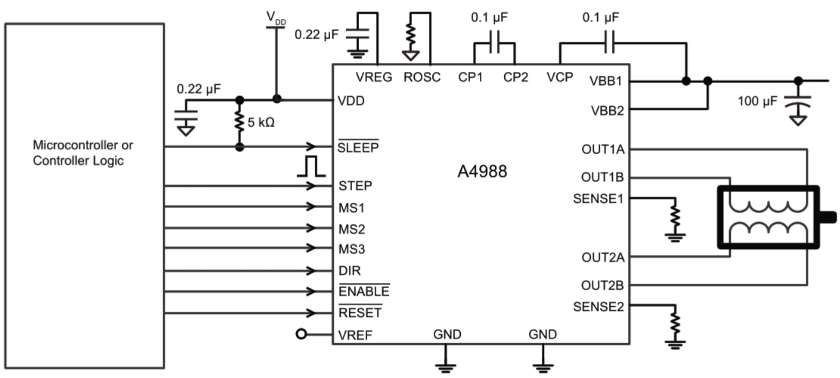
The A4988 is a complete microstepping motor driver with built-in translator for easy operation. It is designed to operate bipolar stepper motors in full-, half-, quarter-, eighth-, and sixteenth-step modes, with an output drive capacity of up to 35 V and ±2 A. The A4988 includes a fixed off-time current regulator which has the ability to operate in Slow or Mixed decay modes.

The translator is the key to the easy implementation of the A4988. Simply inputting one pulse on the STEP input drives the motor one microstep. There are no phase sequence tables, high frequency control lines, or complex interfaces to program. The A4988 interface is an ideal fit for applications where a complex microprocessor is unavailable or is overburdened.

During stepping operation, the chopping control in the A4988 automatically selects the current decay mode, Slow or Mixed. In Mixed decay mode, the device is set initially to a fast decay for a proportion of the fixed off-time, then to a slow decay for the remainder of the off-time. Mixed decay current control results in reduced audible motor noise, increased step accuracy, and reduced power dissipation.

Continued on the next page…

Typical Application Diagram



Description (continued)

Internal synchronous rectification control circuitry is provided to improve power dissipation during PWM operation. Internal circuit protection includes: thermal shutdown with hysteresis, undervoltage lockout (UVLO), and crossover-current protection. Special power-on sequencing is not required.

The A4988 is supplied in a surface mount QFN package (ES), 5 mm × 5 mm, with a nominal overall package height of 0.90 mm and an exposed pad for enhanced thermal dissipation. It is lead (Pb) free (suffix –T), with 100% matte tin plated leadframes.

Selection Guide

Part Number	Package	Packing
A4988SETTR-T	28-contact QFN with exposed thermal pad	1500 pieces per 7-in. reel

Absolute Maximum Ratings

Characteristic	Symbol	Notes	Rating	Units
Load Supply Voltage	V_{BB}		35	V
Output Current	I_{OUT}		±2	A
Logic Input Voltage	V_{IN}		–0.3 to 5.5	V
Logic Supply Voltage	V_{DD}		–0.3 to 5.5	V
VBBx to OUTx			35	V
Sense Voltage	V_{SENSE}		0.5	V
Reference Voltage	V_{REF}		5.5	V
Operating Ambient Temperature	T_A	Range S	–20 to 85	ºC
Maximum Junction	$T_J(max)$		150	ºC
Storage Temperature	T_{stg}		–55 to 150	ºC

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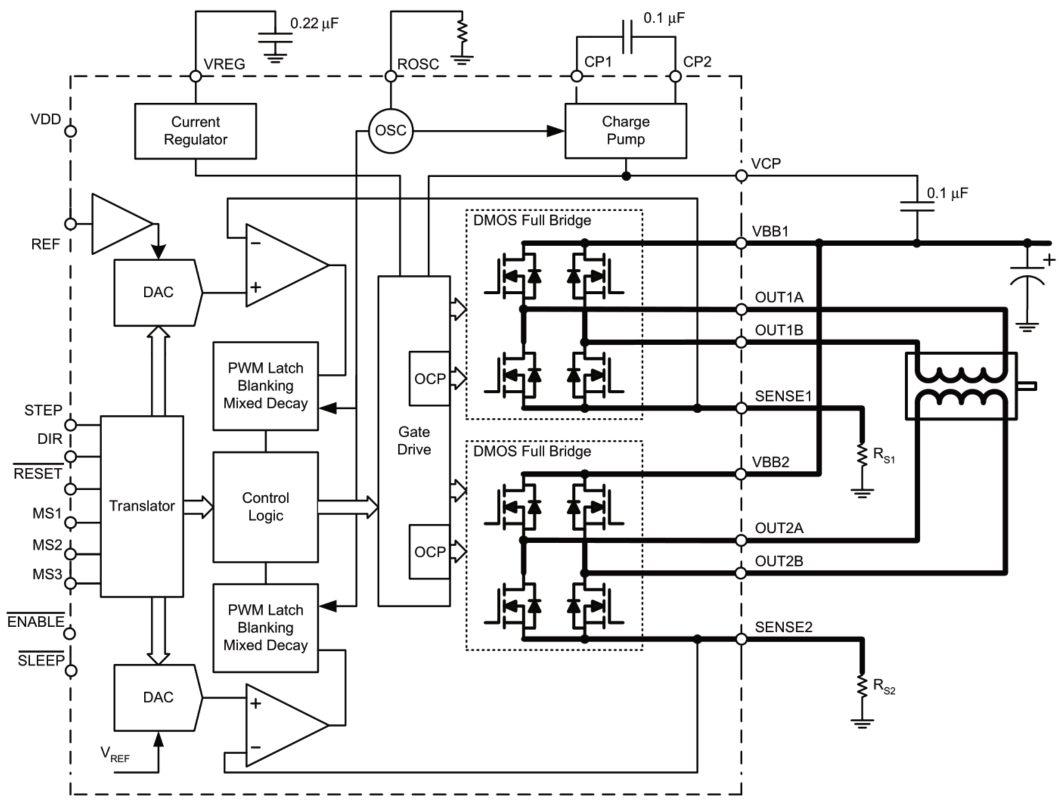
Functional Block Diagram



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ELECTRICAL CHARACTERISTICS[1] at T_A = 25°C, V_{BB} = 35 V (unless otherwise noted)

Characteristics	Symbol	Test Conditions	Min.	Typ.[2]	Max.	Units
Output Drivers						
Load Supply Voltage Range	V_{BB}	Operating	8	–	35	V
Logic Supply Voltage Range	V_{DD}	Operating	3.0	–	5.5	V
Output On Resistance	R_{DSON}	Source Driver, I_{OUT} = –1.5 A	–	320	430	mΩ
		Sink Driver, I_{OUT} = 1.5 A	–	320	430	mΩ
Body Diode Forward Voltage	V_F	Source Diode, I_F = –1.5 A	–	–	1.2	V
		Sink Diode, I_F = 1.5 A	–	–	1.2	V
Motor Supply Current	I_{BB}	f_{PWM} < 50 kHz	–	–	4	mA
		Operating, outputs disabled	–	–	2	mA
Logic Supply Current	I_{DD}	f_{PWM} < 50 kHz	–	–	8	mA
		Outputs off	–	–	5	mA
Control Logic						
Logic Input Voltage	$V_{IN(1)}$		V_{DD}×0.7	–	–	V
	$V_{IN(0)}$		–	–	V_{DD}×0.3	V
Logic Input Current	$I_{IN(1)}$	V_{IN} = V_{DD}×0.7	–20	<1.0	20	μA
	$I_{IN(0)}$	V_{IN} = V_{DD}×0.3	–20	<1.0	20	μA
Microstep Select	R_{MS1}	MS1 pin	–	100	–	kΩ
	R_{MS2}	MS2 pin	–	50	–	kΩ
	R_{MS3}	MS3 pin	–	100	–	kΩ
Logic Input Hysteresis	$V_{HYS(IN)}$	As a % of V_{DD}	5	11	19	%
Blank Time	t_{BLANK}		0.7	1	1.3	μs
Fixed Off-Time	t_{OFF}	OSC = VDD or GND	20	30	40	μs
		R_{OSC} = 25 kΩ	23	30	37	μs
Reference Input Voltage Range	V_{REF}		0	–	4	V
Reference Input Current	I_{REF}		–3	0	3	μA
Current Trip-Level Error[3]	err_I	V_{REF} = 2 V, $\%I_{TripMAX}$ = 38.27%	–	–	±15	%
		V_{REF} = 2 V, $\%I_{TripMAX}$ = 70.71%	–	–	±5	%
		V_{REF} = 2 V, $\%I_{TripMAX}$ = 100.00%	–	–	±5	%
Crossover Dead Time	t_{DT}		100	475	800	ns
Protection						
Overcurrent Protection Threshold	I_{OCPST}		2.1	–	–	A
Thermal Shutdown Temperature	T_{TSD}		–	165	–	°C
Thermal Shutdown Hysteresis	T_{TSDHYS}		–	15	–	°C
VDD Undervoltage Lockout	V_{DDUVLO}	V_{DD} rising	2.7	2.8	2.9	V
VDD Undervoltage Hysteresis	$V_{DDUVLOHYS}$		–	90	–	mV

[1]For input and output current specifications, negative current is defined as coming out of (sourcing) the specified device pin.

[2]Typical data are for initial design estimations only, and assume optimum manufacturing and application conditions. Performance may vary for individual units, within the specified maximum and minimum limits.

[3]V_{ERR} = [(V_{REF}/8) – V_{SENSE}] / (V_{REF}/8).

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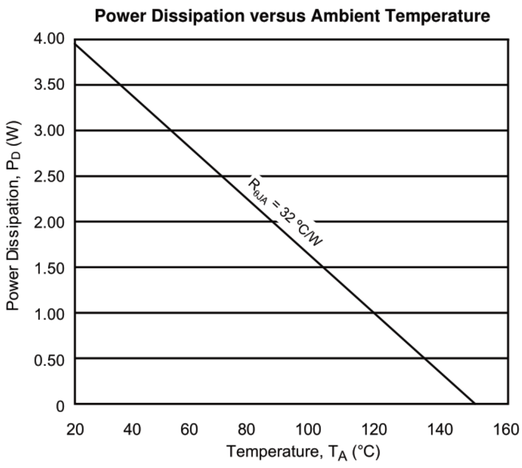
THERMAL CHARACTERISTICS

Characteristic	Symbol	Test Conditions*	Value	Units
Package Thermal Resistance	$R_{\theta JA}$	Four-layer PCB, based on JEDEC standard	32	ºC/W

*Additional thermal information available on Allegro Web site.



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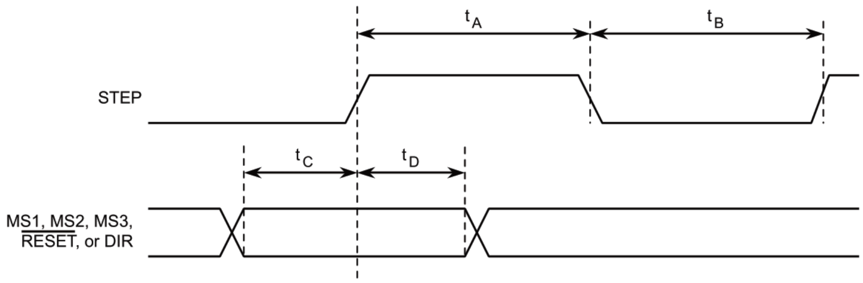

Time Duration	Symbol	Typ.	Unit
STEP minimum, HIGH pulse width	t_A	1	μs
STEP minimum, LOW pulse width	t_B	1	μs
Setup time, input change to STEP	t_C	200	ns
Hold time, input change to STEP	t_D	200	ns

Figure 1. Logic Interface Timing Diagram

Table 1. Microstepping Resolution Truth Table

MS1	MS2	MS3	Microstep Resolution	Excitation Mode
L	L	L	Full Step	2 Phase
H	L	L	Half Step	1-2 Phase
L	H	L	Quarter Step	W1-2 Phase
H	H	L	Eighth Step	2W1-2 Phase
H	H	H	Sixteenth Step	4W1-2 Phase

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Abstract

Nowadays, CNC machines participate in metalworking industries such as machining operations (milling, turning, grinding, etc.), inserting components like PCBs, and drawing. Therefore, in our project, we designed a portable CNC laser-engraving machine for drawing. Our machine is precise, able to process or engrave complex drawings, does not require much space, and does not require an operator with high qualifications (just a simple computer user); also, it is very cheap for purchasing and maintenance. This is due to the open-source software used, the microcontroller board Arduino UNO based on the ATmega328P, the small stepper motors, and the simple mechanisms used to transfer the movement to the 4W laser. In our future work, we will reduce the vibration during the operating time and optimize machine geometry.

Keywords: CNC machines, milling, turning, grinding, PCBs, laser-engraving, Arduino UNO, ATmega328P

ملخص

في الوقت الحاضر تشارك الات CNC في صناعات تشغيل المعادن مثل عمليات التشغيل الالي (التفريز, الخراطة ,القولبة وما الى ذلك) وإدخال المكونات مثل صنع لوحات مطبوعة وأخيرا الرسم في مشروعنا قمنا بتصميم الة نقش بالليزرCNC محمولة ان التنا دقيقة وقادرة على معالجة او نقش التصميمات المعقدة ولا تتطلب مساحة كبيرة ولا تتطلب مستخدم ماهرا (مجرد مستخدم كمبيوتر بسيط) كما انها ارخص للشراء و الصيانة ويرجع ذلك الى البرمجيات مفتوحة ولوحة Arduino UNO للمتحكم الدقيق على أساس ATmega328P, ومحركات السائر الصغيرة والاليات البسيطة المستخدمة الى ليزر 4W , سنعمل مستقبلا على تقليل الاهتزازات اثناء وقت التشغيل وتحسين هندسة الماكينة.

كلمات مفتاحية : الات CNC التفريز, الخراطة ,القولبة, لوحات مطبوعة, نقش بالليزر, لوحة Arduino UNO ATmega328P

Résumé

De nos jours, les machines CNC participent aux industries de la métallurgie telles que les opérations d'usinage (fraisage, tournage, moulage, etc.), l'insertion de composants comme dans les PCB et enfin le dessin. Dans notre projet, nous avons conçu une machine de gravure laser CNC portable pour le dessin. Notre machine est précise, capable de traiter ou de graver des dessins complexes, ne nécessite pas beaucoup d'espace et ne nécessite pas d'opérateur hautement qualifié (juste un simple utilisateur d'ordinateur) ; aussi, il est moins cher pour l'achat et l'entretien. Cela est dû au logiciel open source utilisé, à la carte microcontrôleur Arduino UNO basée sur l'ATmega328P, aux petits moteurs pas à pas et aux mécanismes simples utilisés pour transférer le mouvement au laser 4W. Dans nos travaux futurs, nous réduirons les vibrations pendant le temps de fonctionnement et optimiserons la géométrie de la machine.

Mots clés : Machine CNC, Fraisage, Tournage, Moulage, PCB, Gravure laser, Arduino UNO, ATmega328P