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Design and building CNC engraving router machine using Arduino Uno with GRBL control system

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Abstract: Computer Numerical Control Machines are one of the advances in automatically operated machining technology that can meet the need for complex and high-precision products. CNC machine parts generally have a mechanical and electrical system, also called a machine controller, that uses a Human Machine Interface at a high price. One of the software used to control the CNC machine is Arduino Uno, a PC-based GRBL System with a low price and the same function. This software is not far from the advantages of the HMI panel. Operating the machine with this software is also not that difficult. In this research, we intend to make a CNC machine using the Arduino Uno control system and software with a PC-based GRBL System, making it easier for operators to operate it. The results of the research that has been carried out show that the CNC has a size of 800x600x50mm with a system that is operated well and precisely.
Keywords: *Arduino UNO, CNC machine, GRBL, Stepper motor.*

1. Introduction

Computer Numerical Control (CNC) machines are one of the advances in automatically operated machining technology that can meet the need for complex and high-precision products. CNC can also machine things that conventional machining cannot. Entering data in the form of commands consisting of numbers, letters, and symbols into the form of machine movement controls how it works.

The most commonly used types of CNC machines are CNC milling machines, which usually have three axes of movement, and CNC lathe machines, which are used to make cylindrical objects, which generally have two axes of movement. Steel, aluminum, acrylic, wood, and others are some of the materials that can be processed with CNC. CNC routers are one example of CNC technology used in industry for wood machining

CNC machine parts generally have a mechanical and electrical system, which can also be called a machine controlle

r that uses a high price for a Human Machine Interface (HMI). One of the software used to control the CNC machine is Arduino Uno, a PC-based GRBL System with a low price and the same function. This software is not far from the advantages of the HMI panel. Operating the machine with this software is also not that difficult. This final project is intended to create a CNC machine using the Arduino Uno control system and software with a PC-based GRBL System. It makes it easier for operators to operate it, using stepper motors and working specifically for wood, and discussing the machine instrument system's use.

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2. Literature Review

2.1. Understanding CNC Machines

CNC (computer numerical control) is an update to machine tools that already exist in the industrial world following technological developments because previous machine tools were considered less effective in terms of time and cost. CNC is a machine tool automation system operated by commands, programmed abstractly and stored via storage media. This contrasts previous machine tool habits, usually controlled by hand rotation or simple automation [1].

The birth of CNC (Computer Numerically Controlled) machines dates back to 1952 when John Pearson developed them from the Massachusetts Institute of Technology on behalf of the United States Air Force. Initially, the project was intended to make a unique, complicated workpiece. Initially, CNC machine tools required high costs and large control unit volumes. In 1973, CNC machines were still costly, so few companies dared to pioneer investment in this technology. Since 1975, CNC machine production has been developing rapidly. This development was driven by the development of microprocessors so that the volume of the control unit could be more compact. Nowadays, CNC machines are used in almost all fields. From the fields of education and research that use these tools, various beneficial research results are produced that are not widely used in the daily lives of many people [2] [3].

You will often find CNC machines in medium and large industries to support the production process. CNC machines are divided into 2 (two) types, namely.

2.1.1. CNC Milling Machine

CNC milling machines are tools widely used to shape work objects, such as carving work objects. The resulting workpiece from this machine has a flat surface or other specific shapes (profile, radius, cylindrical, etc.) with a particular size and quality[4]. This machine operates by moving the machine table towards a rotating eye. There are three movements in this machine's working process; the first is the rotating movement of the cutting tool on the main spindle. The second movement is feeding while cutting the workpiece, and the last is the depth of cut movement. The cutting method on this machine is determined based on the relative direction of movement of the machine table to the rotation of the knife [5] [6].

2.1.2. CNC Lathe Machine

The CNC Lathe machine is used when the operator wants to obtain a workpiece with a cylindrical shape. On this machine, the machine's chisel is attached to a machine device called the turret. CNC lathe machines have 2 axes: the Z axis, which is parallel to the spindle and the X axis, which is perpendicular to the spindle. The turret section on a CNC Lathe machine is not much different from the Automatic Tools Changer (ATC) or magazine on a CNC Milling machine. The function of this section is to change the chisel automatically[7]. Apart from that, the turret changing speed is also faster than the magazines. CNC Lathe machines in the modern era are equipped with sophisticated features. The number of turrets on a Lathe machine can be more than 1, so it can carry out two program operations simultaneously [8] [9] [10].

Computer Numerical Control, abbreviated as CNC (meaning "computer numerical control"), is a machine tool automation system that works by hand rotation or simple automation using a cam. This differs from previous practice, where hand rotation typically controlled machine tools. In English, NC is an abbreviation for "numerical control". The first NC machines were made by converting ordinary machine tools in the 1940s and 1950s. In this case, conventional machine tools are equipped with motors that will move the controller according to the points entered into the system by the paper recorder. These machines, which combined mechanical servo motors and analog systems, were soon replaced by analog systems and digital computers. This resulted in the modern machine tool CNC, which has changed the design process[11]. Today's CNC machines are closely tied to CAD programs and are built to handle the challenges of the contemporary manufacturing world. CNC machines can make mass products with the same results and fast machining times with an accuracy of up to 1/100 mm more [12] [13] [14].

CNC Router Machines are Computer-controlled Working Machines that use Numerical Language [15]. This CNC router lathe has three functions or uses:

1. The first function is cutting when operating a computer according to your wishes. So errors in cutting can be minimized.
2. The second use is engraving. So, by using this tool, you can decorate it to look better and seem more unique. So, the resulting product will be very satisfying and beautiful.
3. After cutting and engraving, marking is another use for this CNC-based router machine. The point here is to provide signs on the wood used to make the finishing touch appropriate and neat.

2.2. G-Code and M-Code Programs on CNC Machines

G-codes are functions in the most widely used computer numerical control (CNC) programming languages. G-code is the language engineers use to tell computerized machine tools the paths and operations they need to make something. G-code contains information about the location of tools to do work in a factory. G codes differ from M and T codes, which control factory machinery and equipment. Although G-code is commonly used for numerical control (NC), it is just a component that works with other codes to perform a desired task. The standard version of G-code is known as RS-274D [16].

Other versions of CNC machines have compatibility issues. The G code is a preparation code, so it starts with the letter G in the CNC program and controls the machine. Actions commonly controlled by G-code include rotating the pallet, fast movements, a series of controlled feed movements, creating a cutting object, drilling holes or decorative shapes, controlling feed movement in an arc or straight line, and specifying tool information.

2.3. Product Design

Making products based on specific shapes, sizes, and colors is called product design. The products created are useful and sell value for customers in the targeted sales market. Consumers can change or consume other products over time, so businesses must be able to retain their consumers to remain in market competition. One way is to meet customer needs and desires and improve product quality [17].

He form of a plan called a design or design can be in the form of a proposal, drawing, model, or description to produce an object, system, component, or structure [18] [18] [19].

Planning, designing, building, or engineering are all parts of design. The product can be intangible, such as software, work systems, 3D animation models, etc. Product design is the first activity that attempts to create a product consumers need. Product design aims to produce high-quality products that meet consumer needs so that the product is accepted and can compete with existing competitors. The next step after the design is complete is making a product from the design results. Two groups or people with different skills can carry out these two activities. This means that the designer team carries out the design, and product manufacturing is carried out by the product manufacturing team. [20] [21] [22].

3. Methods

Time Stages of Research Implementation This research was conducted at the Industrial Engineering Department of Malikussaleh University in Jalan Batam, Muara Satu District, Lhokseumawe City. In this research, the author used the following data collection techniques.;

3.1. Literature Study

Literature studies that study literature in the form of concepts or theories sourced from books, journals or articles that support the completion of research.

3.1.1. Design Planning

The design of the CNC engraving router machine is made according to the desired specifications. The design concept is carried out by considering the type of router machine, stepper motor, structural material or machine frame, and the material to be processed.

3.1.2. Making a control system on Arduino Uno

Making a control system on the Arduino Uno determines controller parameter values , which can be done by trial and error until the desired results are obtained by referring to the characteristics of each hardware so that the controller works well on the system.

3.1.3. System Testing

System testing is testing the system created, such as the function of stepper motors and router machines that work well using the trial-and-error method.

3.2. Data Analysis Methods

The control system stability test was carried out by analyzing the results of trial and error in the engraving router machine process regarding the finish and line width of the engraving router machine on the materials used. The test methods carried out in this research are as follows:

1. Testing the control system and function of the router machine by carving lines, shapes, and images.
2. Testing the CNC engraving router machine control system using the parameters of machine movement speed, machine accuracy, and router power
3. Testing the accuracy of the CNC engraving router machine with commands or input into the control system.
4. analyze data from the results of the tests carried out

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3.3. Research Framework

The subsequent research framework will be executed inside the Applied Research Scheme.

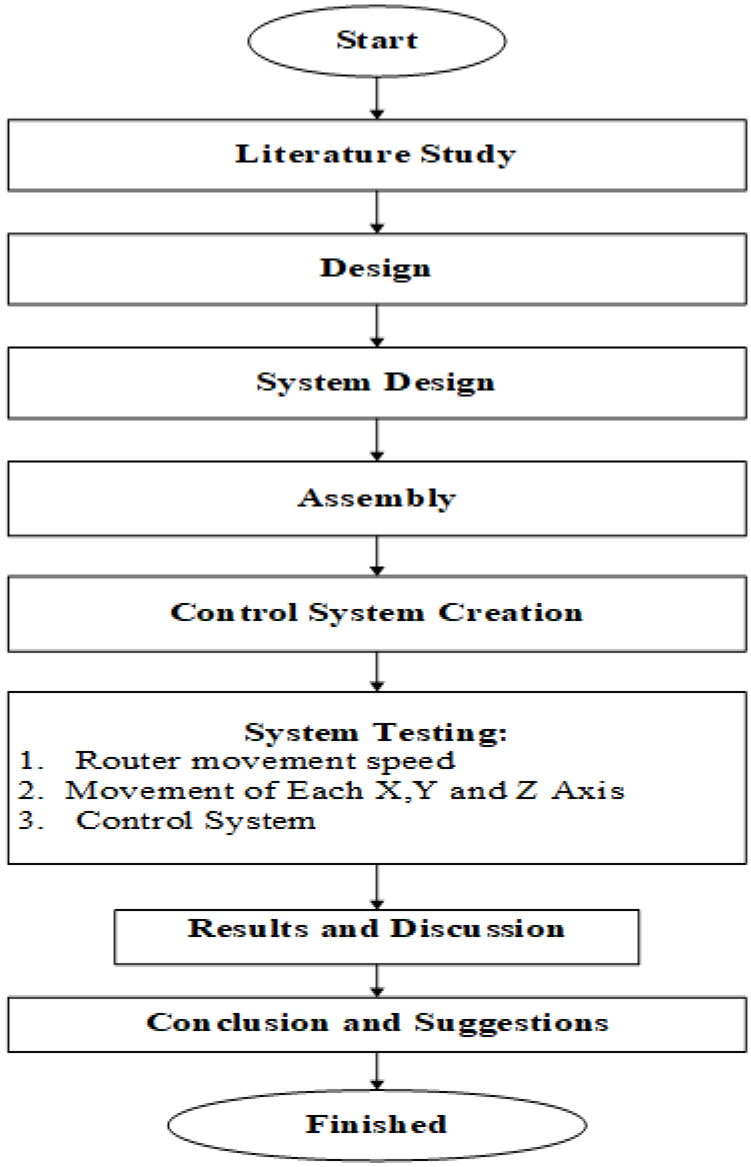

Figure 1.
Research framework.

4. Result and Discussion

A CNC Router Machine is a CNC machine that is used to scrape, cut, and engrave the surface of material using a computer-controlled router machine. This machine has been widely used and is mass-produced by companies/factories with various models. The following are the specifications of the CNC Router machine made by the factory, which can be seen in Table 1:

Table 1.
Factory-made CNC machine specifications.

Brand	Forsun
Control system	NC studio control system
Frame	Iron plate
Voltage	AC220V/50Hz
Dimension (L×W×H)	400×400×120mm
Number of Axes	3
Weight (KG)	400
Working table size (mm)	550×800
Spindle motor power (kW)	1.5

This CNC machine is heavyweight and has relatively small dimensions. The price offered is prohibitive, and operating the machine is more difficult to use.

4.1. CNC Router Machine Design

In this research, the CNC machine design has a size of 800 cm long, 600 cm wide, and 40 cm high, which is made from solid components and is resistant to rust and has a work area size of 795 cm long, 690 cm wide, and 30 cm high. This machine is operated using Openbuilds software with GRBL control as the control system to run this CNC machine, followed by Vectric Aspire software to create designs or

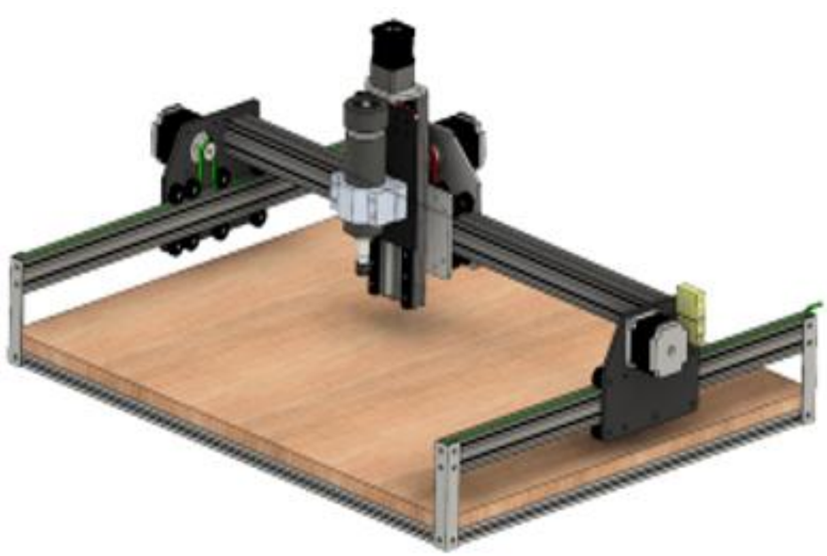

Figure 2.
CNC router machine design.

Edit images that will be used to carve objects on the material you want to carve. The CNC laser engraving machine design drawing can be seen in Figure 2 as follows.
The specifications for the CNC laser engraving machine in this research are as follows:

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Table 2.
CNC laser engraving machine specifications design results.

Create/Editing design software	**Vectric aspire**
Control system	GRBL openbuilds
Frame	Alumunium V-slot and T-slot
Voltage	AC220V/50Hz
Dimension(L×W×H)	600×800×50 mm
Number of axes	3
Weight (KG)	10 kg
Working table size (mm)	590×795
Spindle motor power (kW)	1.5

The tools used in research on the design of CNC engraving router machines can be seen in Table 3. as follows:

Table 3.
List of tools used.

No	**Tool**	**Amount**
1	Drilling machine	1 Units
2	Drill bit	1 Units
3	Hacksaw	1 Units
4	Grinding machine	1 Units
5	Pliers	1 Units
6	Scissors	1 Units
7	Soldering	1 Units
8	Screwdriver	1 Units
9	Ruler	1 Units
10	Sandpaper	1 Units
11	Whiteboard marker	1 Units

The materials used in the CNC engraving router machine design research can be seen in Table 4.as follows:

Table 4.
List of ingredients used.

No	**Material**	**Amount**
1	Arduino Uno	1 Units
2	CNC shield	1 Units
3	Motor stepper	4 Units
4	Driver motor stepper	3 Units
5	Power supply 12 V 15 A	1 Units
6	Router machine	1 Units
7	Jumper cable	1 Set (30)
8	1 meter power cable	1 Units
9	Tis cable	20 Units
10	Lead screw 300 mm	1 Units
11	Rail axle	6 Units
12	Shaft support	8 Units
13	Pillow lead screw	3 Units
14	Clutch	2 Units
15	Bolt-nut	60 Units

16	Linear bearing	8 Units
17	GT 2 Belt	2,2 Meters
18	Frame V-slot	6 Meter
19	Alumunium plate	6 Units
20	Anti-blacklash nut	1 Units
21	Baseboard	1 Units
22	Limit switch	3 Units
23	V- slot nut dan hammber nut	50 Units
24	Pulley GT2	3 Units
25	Bracket corner	10 Units
26	Alumunium spacer	26 nits

4.2. CNC Router Machine Assembly

After selecting components that follow the design, the process for assembling the CNC router machine is as follows.

1. Cut the 2040 V-slot aluminum into 4 units using a grinder measuring 2 units of 800 cm and 2 units of 600 cm, and cut 1 unit of 2080 V-slot aluminum with a size of 25 cm, then clean up the remaining messy cuts using a grinder. Sandpaper.
2. Cut the 2020 T-slot aluminum into 3 units using a grinder with a size of 600 cm and 4 units with a size of 17 cm, then trim off the remaining cutting
3. Cut 3 aluminum plates with dimensions of 160 mm x 100 mm, 110 mm x 160 mm, 80 mm x 80 mm, 160 mm x 180 mm, then trim the ends of each piece of aluminum so that it is not sharp
4. In the 2040 aluminum V slot with a size of 600 cm, 4 threads with a size of M5 are made so that when connecting the aluminum plates, they can stick tightly
5. combine 2020 T-slot aluminum measuring 600 cm with 800 cm to form a rectangle for the bottom frame, then add corner brackets and bolts to each elbow.
6. Combine the 2020 aluminum T-slot measuring 17 cm with the aluminum bottom frame at each corner so that the space for 2040 aluminum measures 800 cm, then add corner brackets and M5 bolts at each elbow.
7. Then combine the V-slot 2040 measuring 800 cm with aluminum which has been supported with a height of 10 cm, and provide corner brackets and M5 bolts at each elbow.
8. Make a hole in the aluminum plate that has been cut to insert the bolt of the specified size
9. Combine the aluminum plate measuring 160 cm x 180 cm with the approximately 2040 aluminum v-slot and the right one using the V-wheel wheel bearing, this functions as the X axis.
10. Install the stepper motor on the 160 cm x 180 cm plate with M5 bolts
11. Combine the 2040 V-slot aluminum measuring 600 cm with the 160 cm x 180 cm aluminum plate which was combined in the previous process using M5 bolts to function as the Y axis.
12. Install the stepper motor on the 160 cm x 180 cm plate with M5 bolts
13. Combine the aluminum plate measuring 160 cm x 180 cm and the aluminum plate 160 cm x 100 cm using a V-wheel wheel bearing and M6 bolts.
14. After completing the process, combine the 25 cm V-slot 2080 aluminum to the plate in the previous method using M5 bolts. This functions as the Z-axis
15. Install the aluminum plate 80 cm x 80 cm above the Z axis, then bolt it to secure it with M5 bolts.
16. Install the stepper motor on the 160 cm x 180 cm plate with M5 bolts
17. Install the clutch on the stepper motor on the Z axis, then install a 30 cm long leadscrew on the leadscrew combined with an anti-backslash nut, then install the pillow bearing at the bottom of the Z axis.
18. The frame-loading process is complete.

The electrical wiring assembly process for the CNC router machine can be seen in Figure 5. as follows:

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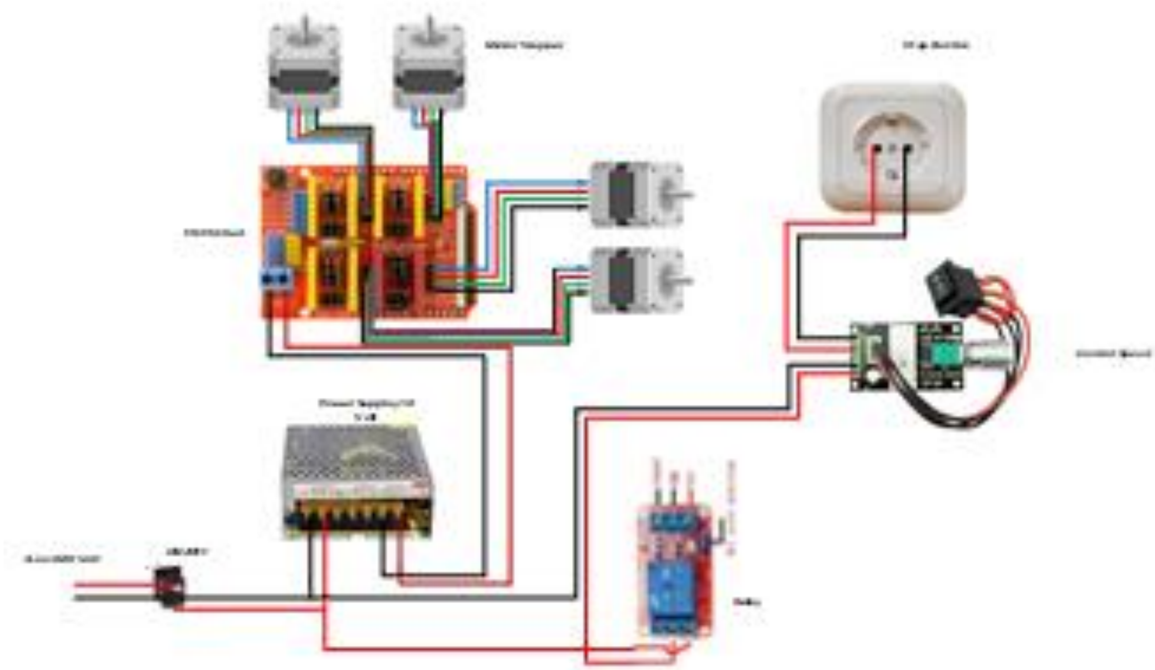

Figure 5.
CNC machine electrical wiring.

4.3. Grbl Configuration in OpenBuild Software

Before operating a CNC machine using OpenBuild software, you must look at the communication settings between the PC/Laptop and the microcontroller. Calibration is also needed first so that the distance between the program and the actual is the same. Here is how to set open builds:

1. Openbuilds software book for configuration

Figure 6.
Home display in Openbuilds software.

4.3.1. Then, Connect Arduino to OpenBuids

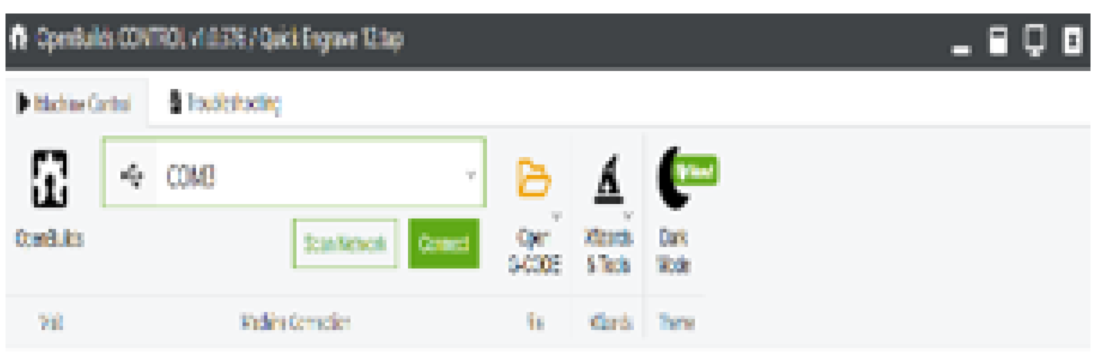

Figure 7.
Connect to Arduino.

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4.3.2. Then Open GRBL Settings to Configure.

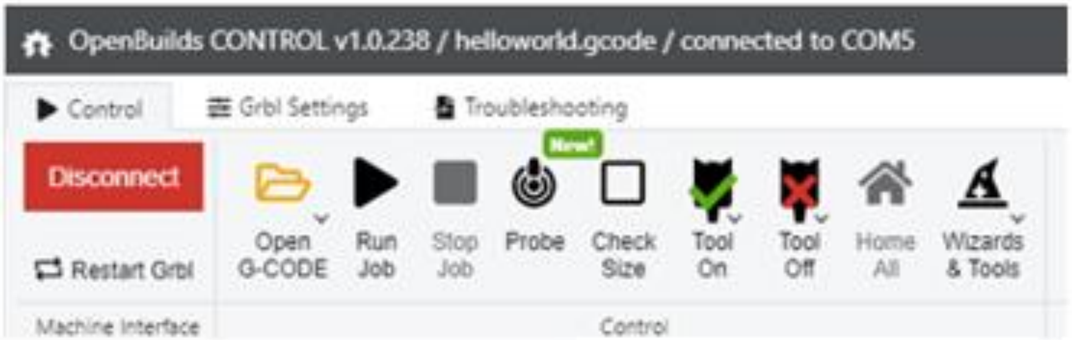

Figure 8.
Grbl settings.

4.3.3. Then Press Save

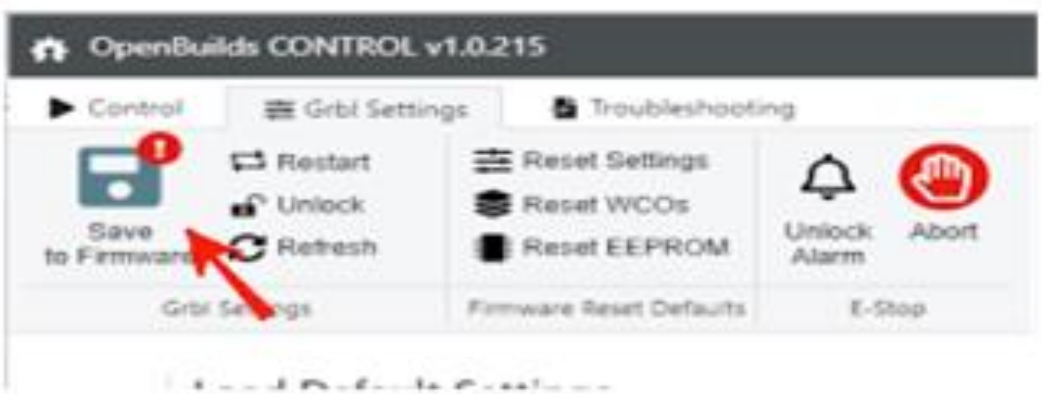

Figure 9.
Save to firmware.

4.4. CNC Machine Testing

Performance testing of the CNC engraving machine was carried out using day parameters, router movement speed for each axis, and the control system. To determine the values of the parameters used in the CNC engraving router machine operating process.

4.4.1. Router Travel Speed Testing

The router movement speed test can be seen in Table 5 as follows:

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Table 5.
Router travel speed testing.

No	Experiment	Desired distance (mm)	Axis movement speed(mm/min)	Router movement speed	Results
1	Point X-to X+	80	500	100%	
2	Point X+ to X-	80	500	75%	
3	Point Y-to Y+	80	500	50%	
4	Point Y+ to Y-	80	500	25%	

Based on router speed testing, which has been carried out on wood material with router speed parameters of 100%, 75%, 50%, and 25%, the correct parameters are obtained, namely to be above 25% because, for a speed of 25%, the rotation is unstable and can cause the router bit is broken.

4.4.2. X-Axis Movement Testing

The X-axis movement test for a distance of 80 mm can be seen in Table 6 as follows:

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Table 6.
X-axis movement testing for a distance of 80 mm.

No	Experiment	Desired distance (mm)	Actual distance (mm)	***Backlash*** (mm)
1	Point X-to X+	80	80.12	0,12
2	Point X+ to X-	80	80,14	0,14
3	Point X-to X+	80	80,11	0,11
4	Point X+ to X-	80	80,17	0,17
5	Point X-to X+	80	80,12	0,12
6	Point X+ to X-	80	80,15	0,15
Average backlash				0,135

The results of this test showed an average backlash of 0.135 mm. With a considerable backlash value, there is a delay in the movement of that value, thus affecting the tool's accuracy. This is stated due to the inaccurate pitch of the belt used and between the drive pulleys.

4.4.3. Y-Axis Movement Testing

The Y-axis movement test for a distance of 80 mm can be seen in Table 7 as follows:

Table 7.
X-axis movement testing for a distance of 80 mm.

No	Experiment	Desired distance (mm)	Actual distance (mm)	***Backlash*** (mm)
1	Point Y-to Y+	80	80,08	0,08
2	Point Y+ to Y-	80	80,13	0,13
3	Point Y-to Y+	80	80,10	0,10
4	Point Y+ to Y-	80	80,04	0,04
5	Point Y-to Y+	80	80,14	0,14
6	Point Y+ to Y-	80	80,17	0,17
Average backlash				0,11

The results of this test showed an average backlash of 0.11 mm. With a considerable backlash value, there is a delay in the movement of that value, thus affecting the tool's accuracy. This is stated due to the inaccurate pitch of the belt used and between the drive pulleys.

4.4.4. Z-Axis Movement Testing

The X-axis movement test for a distance of 5 mm can be seen in Table 8 as follows:

Table 8.
Z-axis movement testing for a distance of 5mm.

No	Experiment	Desired distance (mm)	Actual distance (mm)	***Backlash*** (mm)
1	Point Z-to Z+	5	4,90	0,10
2	Point Z+ to Z-	5	4,97	0,03
3	Point Z-to Z+	5	4,98	0,02
4	Point Z+ to Z-	5	4,90	0,10
5	Point Z-to Z+	5	4,96	0,04
6	Point Z+ to Z-	5	4,98	0,02
Average backlash				0,051

The results of this test showed an average backlash of 0.051 mm. With a considerable backlash value, there is a delay in the movement of that value so that it does not affect the tool's accuracy. This is stated due to things such as a lack of precision in the pitch of the lead screw used. Apart from that, it is also caused by connecting the lead screw using a flexible coupling which still has flexibility when rotating.

5. Conclusion

From the results of the research that has been done, the conclusions that can be obtained are as follows:

1. The machine that has been made can machine wood with 600mm x 800mm x 50mm dimensions. With sufficient precision, the average backlash on the X axis = 0.135mm, the Y axis = 0.11mm, and the Z axis = 0.051mm. The total average is 0.098mm, and the router speed can be adjusted according to the work being done.
2. The controller system uses Arduino Uno and GRBL software, and the control software uses Open Builds, which has a fast response and easy configuration because there is an auto-calibration feature on each axis to determine the precision of the distance. A feature regulates the movement system on the stepper motor that we use on the machine. Using open builds software does not require costs and is easy to use.

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