DIY STANDALONE 3-IN-1 PCB CNC MACHINE

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Abstract

CNC router (Computer Numerical Control router) is a kind of machine that is used for cutting wood, metal or stone. CNC is computer-controlled and uses CAM (Computer-Aided Manufacturing) software that makes CAD files into its own programming language. Manufacturing using CNC machines are extended to carvings, decors, panels, frames, moldings and so on. The study is an innovation of the CNC PCB machine that aims to help students of Baliuag University to effectively use PCBs in projects and other course required laboratory works. The researchers recycled scraps of wood and aluminum and other electronic parts that can still be used. They considered installing dedicated computer with monitor for interaction. Schematic diagrams which are usually used by the students in laboratories, projects and activities required of the courses were sourced from faculty of the ECE Department of CEDE. The said schematic diagrams were predesigned into built-in computer readily for use.

Keywords: CNC PCB Machine, Printed Circuit Board (PC*B), schematic diagrams*

Technology develops rapidly and the advancements in the field of electronics has gone fast. Thus, because of the quick upgrades with the specifications of every hardware, there is more possibility that the existing devices would soon be eliminated and newly developed electrical and electronic components will be used. With such development, the physical sizes of those electrical and electronic components vary; they can be smaller or bigger than before, however more sophisticated and smarter.

The improvements in electronics and technology are caused by the great minds of people implementing their

knowledge about circuit theories. These circuit theories come to life through the use of schematics and circuit layouts. Schematics and circuits are likely to be connected in "point-to-point wiring" also known as "rat's nest wiring" before. Point-to-point construction is a non-automated strategy for the development of electronic circuits and is broadly utilized before the presence of printed circuit boards (PCBs). Automated assembly gradually became widespread following their introduction in the 1950s. Point-to-point construction is a kind of electrical connection which is not suitable for automation and is carried out manually, making it both more expensive and more susceptible to wiring errors. (Revolvy)

In this case, people come up with means to make the connection more convenient and that was the start of the creation of circuit boards. Albert Hanson (primitive circuit board), Charles Ducas (‘printed wires’), Paul Eisler (first PCB) and many other personalities became the pioneers in creating PCBs.

Printed Circuit Board (PCB) is an electronic circuit utilized as a part of devices to give power-driven support and pathway to its electronic segments. It is made by joining diverse sheets of non-conductive material, like fiberglass or plastic, which effectively holds copper connections. A PCB can hold different electronic parts that might be bound without utilizing visible wires, which simplifies its use. PCBs become widely used for electronics. It was ready-made produced and each has a premade layout according to its circuit function which is available commercially. This is also important not just for the industry, but also for education.

The production and manufacturing of PCB in the present can only be attained if one has manufacturing facilities which have big milling machine with etching formula.

The milling machine is controlled through large conveyors and is Computer Numerical Controlled (CNC) via certain computer unit. Computer Numerical Controlled (CNC) is the automation of machine tools by means of computers executing pre-programmed sequences of machine control commands. CNC Machining is a process used in the

manufacturing sector that involves the use of computers to control machine equipment. Machines that can be controlled in this manner include lathes, mills, routers and grinders. (Thomasine, 2014)

The first commercial CNC machines were built in the 1950's, and ran from punched tape. While the concept immediately proved it could save costs, it was so different that it was very slow to catch on with manufacturers. However, a number of key developments brought CNC rapidly along during the 1960's including the invention of "gcode" which acts as the language of NC and the availability of CAD files for this machining. CNC continuously develop which can now control various applications.

On the other hand, customized PCB layouts can also be attained by the use of etching techniques. With the development of board lamination and etching techniques, this concept evolved into the standard printed circuit board fabrication process in use today. Etching techniques can be divided into wet etching and dry etching where chemical solution is used in wet etching through chemical reactions in order to achieve the purpose of etching while dry etching is usually a plasma etching. (L. Gong, 2017)

Wet etching is a more common way in prototyping a circuit board used in educational projects for its availability in electronics stores. However, these kinds of PCB etchant solutions are nasty by definition and purpose. They eat metal and give off toxic fumes. They contain metal that can only be called toxic waste, and should be treated as such but was indispensable to etching process. (pcbhowto.com, 2017)

The researchers thought of a way where they can create a project which allows students to make their own circuit layout into PCB by the use of CNC technology instead of the use of complicated miller machines and prevents the students from exposure to etching chemicals.

Problem Statement

The general goal of this study is to design and to create a DIY machine that could be used for prototyping PCBs for Electronics courses using CNC technology. Hence, the study pursued answers to the following queries:

1. What type of machine can be used in prototyping PCBs automatically?
2. What makes the machine to be a DIY project that is made from scrap material?
3. What features the machine possesses that other existing similar machines do not have?
4. What are the predesigned circuit layouts included in the machine's software?
5. What are the parameters to be tested and evaluated to determine effectiveness and efficiency of the machine?

Methods

Conceptual Framework

The study utilized the conceptual diagram presented in Figure 1 in designing the DIY Standalone 3-in-1 PCB CNC Machine. The study adopted the IPO Model. The Inputs necessary for the development of the study included widely used circuit layouts and its theories, with the knowledge on the system's software and programming, and the approval and suggestions of their professors. The process by which the project was developed used several procedures which are; designing the whole body frame of the CNC and position of its motor and belts, having built-in tiny computer monitor ready-to-use, and having pre-designed PCB layout for Electronics course. The process was followed for the full construction of DIY Standalone 3-in-1 PCB CNC Machine with User's Manual to guide its users.

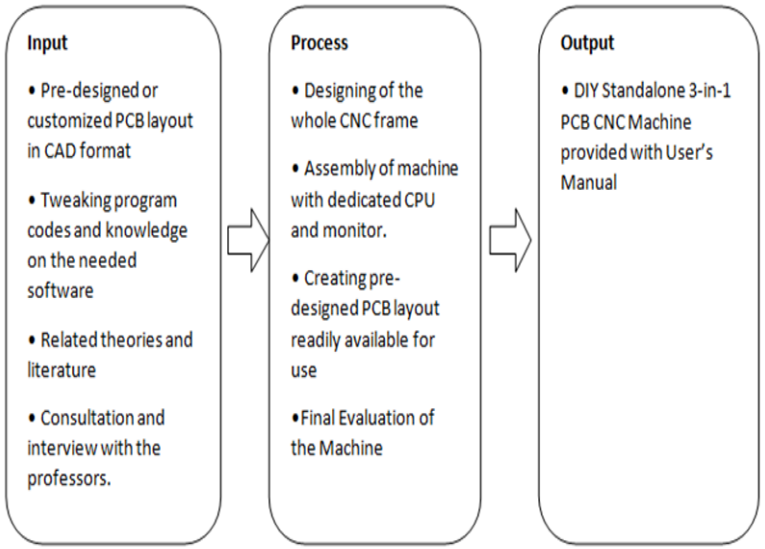


Figure 1. The basic IPO model of DIY Standalone 3-in-1 PCB CNC Machine

Data Gathering Procedures

Data gathering is an important procedure when conducting a study for better understanding of the theoretical framework. The researchers collected facts through the use of the evaluation of related literature and understanding about the CNC machine. They also asked their professors who have expertise regarding the subject on how they can probably do and accomplish the study. They did research to get more specific facts on how they could pursue it successfully. As they gathered all the information they wanted, they thoroughly investigated how the machine would work with the purpose to begin making the DIY Standalone 3-in-1 PCB CNC Machine.

According to Wyse (2011), Qualitative Research is fundamentally exploratory research. It is utilized to pick up a comprehension of hidden reasons, assessments, and inspirations. It gives bits of knowledge into the issue or creates thoughts or theories for potential quantitative research.

Using the internet and interviews with professors, the researchers observed thoroughly how CNC machine work by watching different videos on the internet and they also used articles and journals to know how CNC machine is operated and studied old thesis reports to easily demonstrate and visualize the project plan to make. Based on the theoretical analysis, the information gathered were used as a basis on how the researched materials can be used as guide for the construction of the PCB CNC Machine.

According to Richey (1994), Developmental Research has been defined as the systematic study of designing, developing, and evaluating instructional programs, processes, and products that must meet criteria of internal consistency and effectiveness.

The DIY Standalone 3-in-1 PCB CNC Machine is designed to help the engineering students to be able to facilitate the laboratory work more efficiently in a safer and faster pace.

Block Diagram

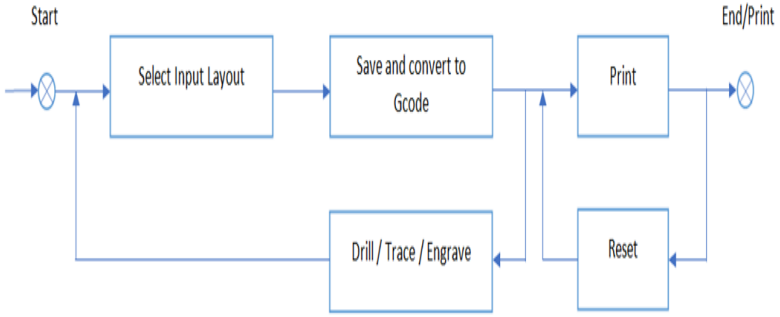


Figure 2. Block Diagram of DIY Standalone 3-in1 PCB CNC Machine

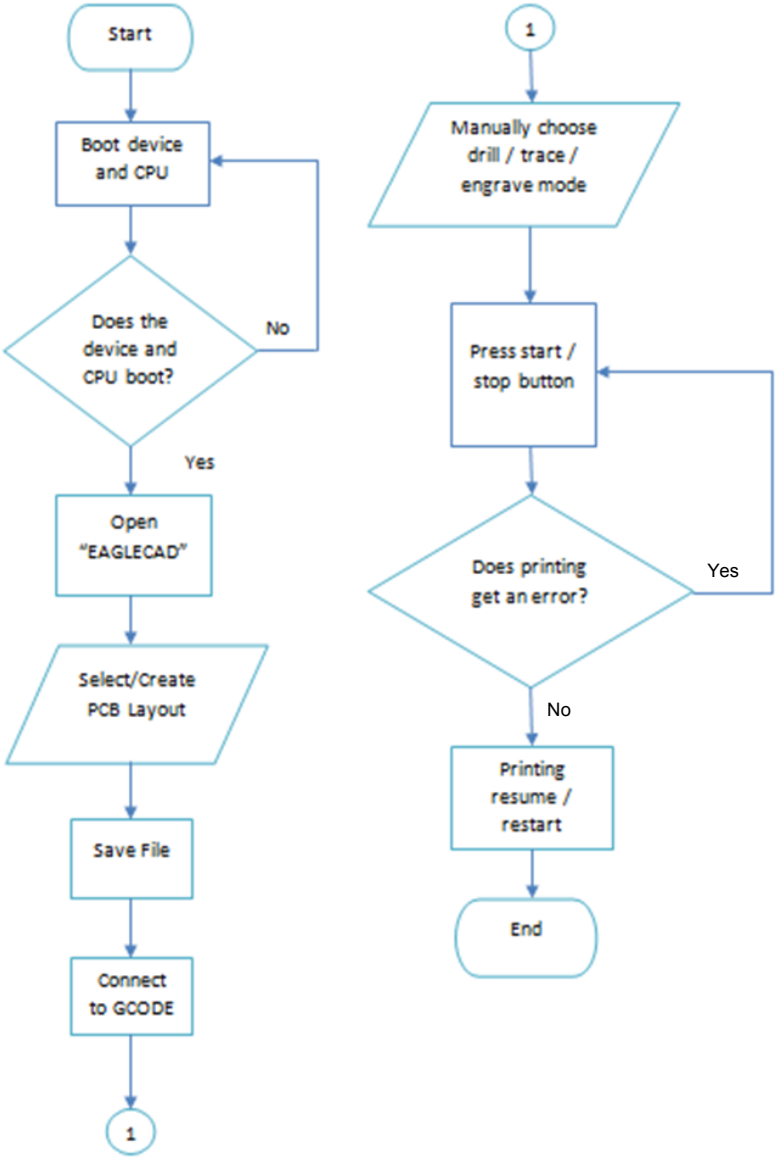


Figure 3. Flow Chart of DIY Standalone 3-in-1 PCB CNC Machine

Design Components

The DIY Standalone 3-in-1 PCB CNC Machine is a mix of different components. This section displays the purpose and specification of the components.

- **UDOO x86 Basic**

UDOO X86 Single Board PC is a powerful, Intel-powered, Linux/Windows/Android computer with an Arduino 101-perfect module installed on a similar board. This served as the miniature CPU of the project study.

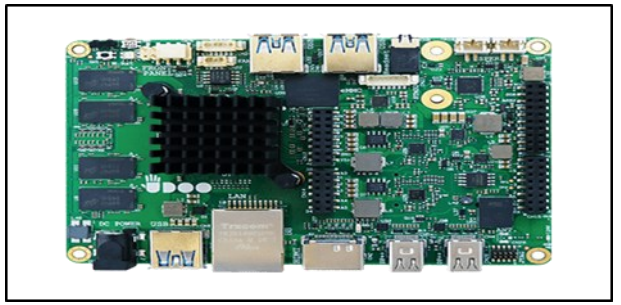


Figure 4. UDOO x86 Basic

Table 1. Specification of UDOO x86 Basic

Parameter	Description
CPU	Intel Atom X5-E8000 2.00Ghz & Intel Quark SE core
	32MHz plus32-bit ARC core 32MHz
GPU	Intel HD Graphics, up to 320MHz12 execution units
RAM	2GB, DDR3L
Interface Type	Ethernet, HDMI, UART, USB
Dimensions	120 mm x 85 mm
Brand	UDOO
Description/Function	Basic X86 maker board

- **LCD Screen**

The 7” touch screen monitor for UDOO gave the researchers the ability to control the device in designing the PCB layout.

Figure 5. LCD Screen

Table 2. Specification of LCD Screen

Parameter	Description
Display Screen	7” Touchscreen Display
Screen Dimensions	194mm x 110mm x 20mm (including standoffs)
Viewable screen size	155mm x 86mm
Screen Resolution	800 x 480 pixels
Other Kit Contents	Adapter board, Display ribbon cable, 4x Jumper wires, 4x Stand-offs and Screws

- **Stepper Motor**

Stepper motors are DC motors that move in discrete steps. By energizing each phase in sequence, the motor will rotate one step at a time.

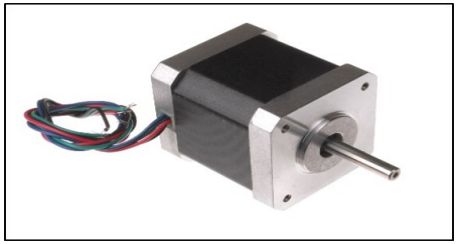


Figure 6. Stepper Motor

Table 3. Specification of Stepper Motor

Parameter	Description
Rated Voltage	DC 24V
Working Voltage	DC 21.6~26.4V
Rated Current/Phase	400mA(Peak) 600mA(Peak)
Coil DC Resistance	13.5 /phase±10% 13 /phase±10%
Step Angle	7.5°/step 3.75°/step
Drive Method	Constant Current
Excitation Method	2-2 Phase excitation (Unipolar driving)
Insulation Class	Class E insulation
Holding Torque	33mN·m 35mN·m
Pull-out Torque	21.3mN·m/1,000pps 26.3mN·m/1,000pps
Pull-in Torque	26.1mN·m/300pps 29mN·m/600pps
Max. Pull-out Pulse Rate	1,790pps 1,600pps
Max. Pull-in Pulse Rate	630pps 1,200pps

- **Timing Pulley**

This type of timing pulley was used for precise motion control, a perfect partner for timing belt.

Figure 7. Timing Pulley

- **Timing Belt**

This type of belt was used to transfer rotational motion from a stepper motor into linear motion along a rail.

Figure 8. Timing Belt

Description:

6mm Belt
20 tooth
5mm Bore

- **CNC Shield V3**

CNC shield V3.0 was used as drive expansion board for engraving device for 3D printer and different devices. There are 4 slots in the board for stepper motor drive modules which can drive 4 stepper motors, and every stepper motor needs 2 IO ports. This is to mention that the 6 IO ports can properly work with three stepper motors.

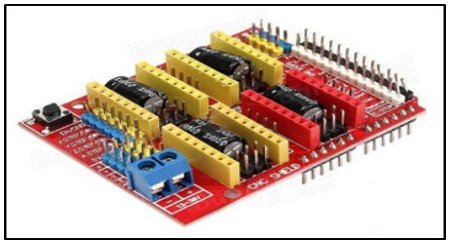


Figure 9. CNC Shield v3

Description:

- Latest Arduino CNC Shield Version 3.10
- GRBL 0.9 compatible
- PWM Spindle and direction pins
- 4-Axis support (X, Y, Z , A-Can duplicate X,Y,Z)
- 2 x End stops for each axis

- **DRV8825 Stepper Motor Driver**

DRV8825 Stepper Motor Driver was installed to the CNC shield v3. It controlled the direction of stepper motor.

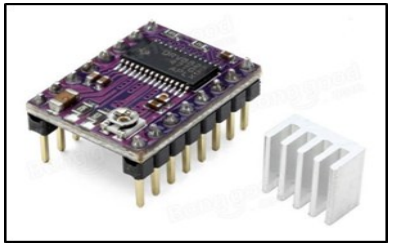


Figure 10. DRV8825 Stepper Motor Driver

Table 4. Specification of DRV8825 Stepper Motor Driver

Parameter	Description
Operating voltage	8.2V - 45VDC
Continuous current per phase	1.5 A2
Maximum current per phase	2.2 A3
Minimum logic voltage	2.5 V4
Maximum logic voltage	5.25 V4
Microstep resolutions	Full, 1/2, 1/4, 1/8, 1/16, and 1/32
Reverse voltage protection	No

- **12V – 4.2A Switch Power Supply**

12V – 4.2A Switch Power Supply was used for powering the CNC shield v3,drill and fan.

Figure 11. 12V – 4.2A Switch Power Supply

Table 5. Specification of 12V – 4.2A Switch Power Supply

Parameter	Description
Current Output	4.2 A
Input Type	AC 110-220 V
Output Type	DC 12 V
Dimension (L x H x W)	78.2 x 37 x 111 (mm)
Product Weight	216 g

- **Mini Electric Drill**

Mini Electric Drill was used to hold the drill bit for etching the circuit design into PCB board

Figure 12. Drilling Tool Holder

Table 6. Specification of Mini Electric Drill

Parameter	Description
Voltage Supply	220v/240v
Weight	approx. 2.5kg
Power Consumption	180W
Speed	8,000 - 30,000 r/min

- **PCB Engraving Bit**

PCB Engraving Bit is a high hardness, wear resistance and strength and also super sharp tool bit which helped when drilling through PCB. The drill bits also do not easily bend or break.

Figure 13. Engraving Bits

Table 7. Specification of Engraving Bits

Parameter	Description
Material	Tungsten steel
Color	Silver, golden
Shape	V-shape
Degree	15°
Shank diameter	3.175mm
Cutting edge diameter	0.1 mm
Total length	35mm

- **SanDisk Ultra Fit 64GB USB 3.0 Flash Drive**

SanDisk Ultra Fit 64GB USB3.0 Flash Drive was used as the main storage of the UDOO x86 basic. It was also a bootable USB because all files and applications that are used in DIY Standalone 3-in-1 PCB CNC Machine are stored in USB.

Figure 14. SanDisk Ultra Fit 64GB USB 3.0 Flash Drive

- **Female Dupont**

Female Dupont was used to connect the 2 terminals like Arduino Uno and Easy Driver Stepper Motor via jumper wires.

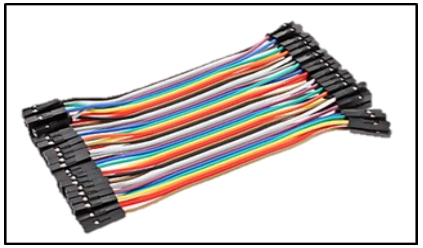


Figure 15. Connecting Wires

- **#22 AWG Stranded Wire**

This type of wire was used to connect all the switches and push buttons to the CNC shield v3 and power supply.

Figure 16. #22 AWG Stranded Wire

- **Push Buttons**

The Push Buttons were used as the limit switches and control button for stop, resume, abort and emergency stop button. Limit switches served as the tool that tells the computer the limits of the DIY Standalone 3-in-1 PCB CNC machine. When one of the axes moved to an axis limit, the switch is activated and the machine stops. These limit switches were also used to inform the computer of the home position.

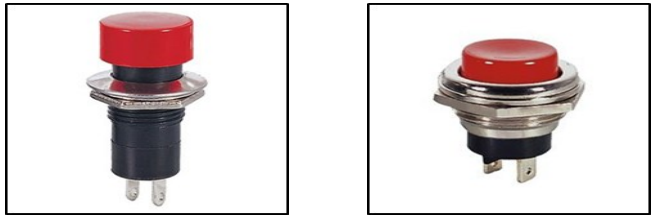


Figure 17. Push Buttons

- **Switch**

Switch was used as the main on-and-off switch of the project design.

Figure 18. Switch

- **Linear Guide Rail**

Linear Guide Rails were used in Y and Z axis for their optimal stability.

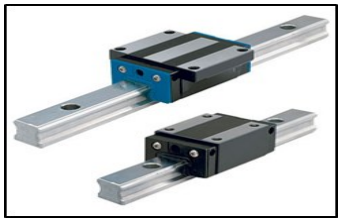


Figure 19. Linear Guide Rail

- **Aluminum**

Aluminum angle bar was used as the body frame/case of the project design and to make the project design durable.

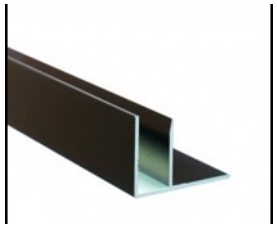


Figure 20. Aluminum

- **Bearing**

It was used for the optimal stability of the X-axis.

Figure 21. Bearing

- **Bolt and Nut**

Bolts and Nuts were used to steady the PCB board to the platform of X-axis and to fix the linear guide rail of Z-axis.

Figure 22. Bolt and Nut

- **Extension Chord**

The Extension Chord is a multiple socket allowing multiple electrical devices to be powered from a single electrical socket. It was used to power the 12V – 4.2 switch power supply and the UDOO x86 basics.

Figure 23. Extension Chord

- **Cooling Fan**

Cooling fan was reused to ventilate heated air from the heat sink of UDOO x86 Basics and CNC shield v3.

Figure 24. Cooling Fan

- **Wood**

This type of wood was used as a scrap wood for the platform of X-axis and the foundation of the Z-axis.

Figure 25. Plywood

Assembly and Testing

This section presents the total assembly of the machine. This also includes the testing and changing of parts as the researchers see the best fit for the machine to give its best maximum performance available.

Assembly of Body Frame

Figure 26. Assembly of Body Frame

The researchers decided to make two-parts machine. First is the storage and controls, where engravers, drill bit and tracer to be placed. Power supply, mini PC, CNC shield and driver motor also planned to be stored. The second is the actual machine where the process of engraving, drilling and tracing are done.

The body frame consisted of aluminum, steel rods and

wood scraps. Aluminum parts were joined using rivets. Steel rods were placed into holes in aluminum as the railings or guide for platform and woods for flooring, platform, and supports.

Adding the Details of the Body Frame

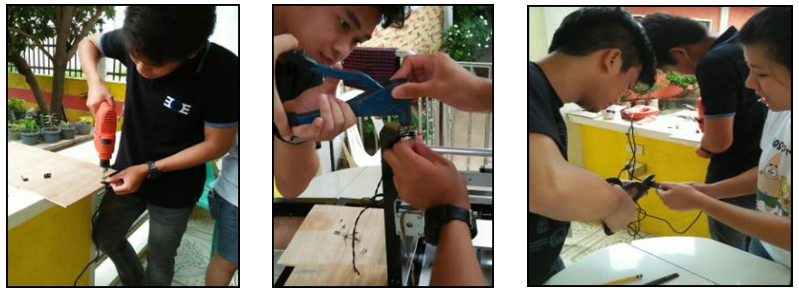


Figure 27. Adding the Details of the Body Frame

Smaller aluminum and wood scraps were used for the details such as holders and fixers.

Calibrating the Motors

Figure 28. Calibrating the Motors

The motors were calibrated using multimeter. The desired values for two motors are 165mV and 825mV for another one. These ratings were measured at the motor driver connected to CNC shield. It can be adjusted using the potentiometer connected to the motor driver.

Fixing Motor Wires

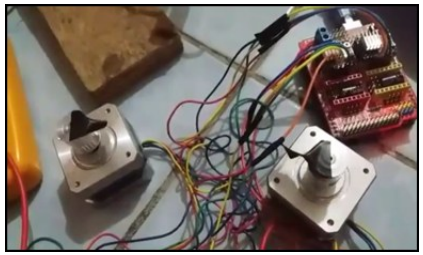
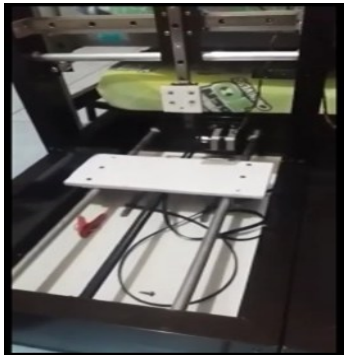


Figure 29. Fixing Motor Wires

The stepper motor wires were extended using dupont to connect it easily to the CNC Shield. CNC shield offered female sockets so male duponts were used for extension. Also the push button switches and controls were extended with male duponts.

Fixing Motors in the Body Frame and Putting Belts and Platforms and other parts



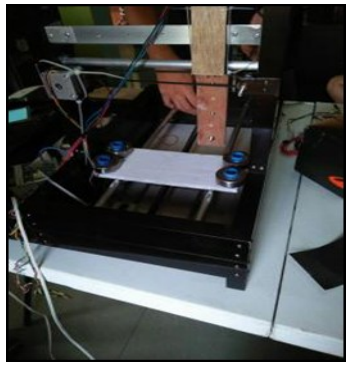


Figure 30. Fixing Motors in the Body Frame and Putting Belts and Platforms and other parts

Motors, pulleys, belts, platforms, and push buttons were fixed into their proper places. X and Y axis motors used aluminum glue to fix and cable tie for support, while Z axis used bolt and nuts to hold in place. Belts were nailed into the wooden platforms and supports. Four bearings were added to X-axis

platform for better friction and guide for the track. Pulleys were secured via long screw and glued nuts.

Initial Testing (with ballpoint pen)

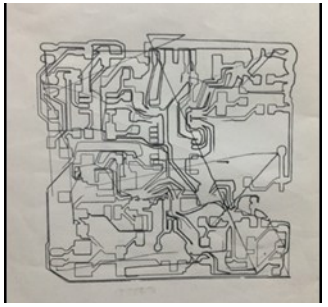


Figure 31. 1st Testing (with ballpoint pen)

A 0-24v power supply was tested to be printed out using ballpoint pen. The results were halfway good as it gave clear image but other parts were blurry and the lines were distorted

Fixing the Drill in the Z-axis

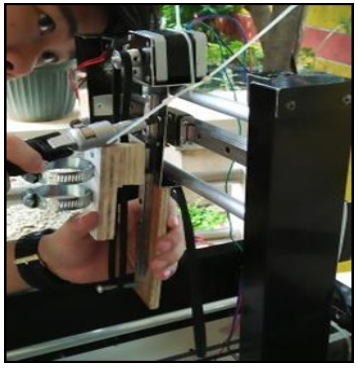


Figure 32. Fixing the Drill in the Z-axis

For better stability and to reduce the distorted lines from previous testing, the researchers tightened the bolts and hose clamps along the Z-axis.

Secondary Testing

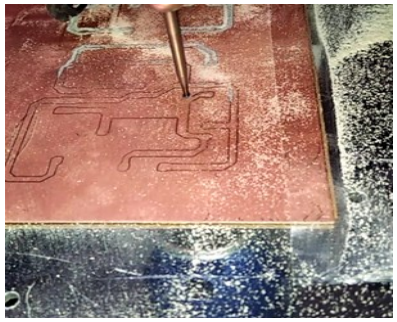


Figure 33. Secondary Testing

The researchers tried to engrave a sample of 5V Power Supply circuit layout. The printing was accurate but some parts were only traced or marked because the platform was not levelled properly.

Final Testing

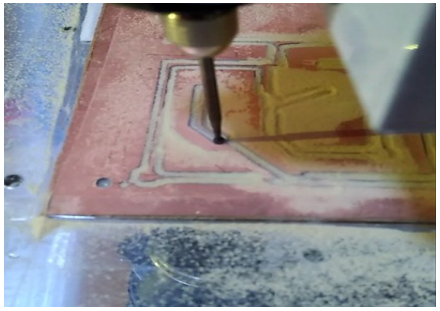


Figure 34. Final Testing

The researchers tried to engrave a sample of JFET circuit layout. The researchers increased the distance of each line in the software to avoid overlapping of engrave. The x-axis platform was also adjusted to engrave every part of the PCB.

Summary

The study aims to design and to create a DIY machine that could be used for prototyping PCBs for Electronics course by the use of CNC technology. It sought answers to the following problems;

- **What type of machine can be used in prototyping PCBs automatically?**

CNC router machine (Computer Numerical Control router machine) is a programmable machine that uses coordinates (x, y, z) as its guide through the workplace area. It uses stepper motors with controllers to move the spindle. As CNC is widely used for cutting wood, metal and stone, the researchers capitalized on its functionality for smaller scale and be used into PCBs.

With coordinates (x, y, z), which is the same as coordinates of schematic diagrams, the PCB design layouts were fed to the motor controllers. The motors moved accordingly, which resulted to printing-like output.

- **What make the machine to be a DIY project that is made from scrap materials?**

The researchers took advantage of their resources as they used scrap woods and aluminums bars for holders and fixes with the help of rivets. Woods were used as platforms and supports. Aluminum angle bars were used as mounting of motors and holders for push buttons. Also stainless rods were used as railings for axes.

- **What features the machine possesses that other existing similar machines do not have?**

The project offered a built-in computer with monitor packed with keyboard and mouse for interaction. This made the study a standalone as the whole machine was complete on its own. The project also offered 3-in-1 purpose, drilling, engraving and tracing ability. The users only need to provide their own PCBs, select existing layouts or draw their own, and print out.

The project also offered predesigned circuit layouts ready to be used by aspiring engineers of the university.

- **What are the predesigned circuit layouts included in the machine's software?**

The researchers asked the professors of Electronics course at the Baliuag University regarding the frequently used PCB design layouts for laboratories, projects and activities based on their experience in teaching Electronics course. Power Supply, AM/FM Radio Receiver, Amplifier, H-Bridge, Censored Switches, Automatics with Timer are some of the built -in circuit layouts.

- **What are the parameters to be tested and evaluated to determine effectiveness and efficiency of the machine?**

The researchers tested the power consumption of the whole machine by testing from different houses and different power sockets. The power reading from five different sockets of different houses showed variation from 213v to 236v. Connected to that, the stepper motor drivers voltage reference may range from 163m V-168mV, 847mV-853mV and 747mV-753mV. Also the power supplied to the drill was also considered as it affected the timing of programmed movement for z-axis if the power supplied was reduced lower than 12v, 2mW.

As the researchers tested the machine, they noted that the machine was fully working, gave an output as duplicate of the input. The machines accuracy was also tested by engraving PCBs regularly. The researchers proved that the machine is ready to be used for long term usage.

Conclusion

As the researchers ventured deep into designing, assembling and testing of the DIY CNC machine, they concluded that:

As an electronics engineer, PCB boards is one of the essential component of an electronic project. It serves as the skeletal frame of the project, laboratory experiments and

activities. There are already pre-made PCBs that can be bought but fitting all electrical and electronics components are hard. Thus making own PCB layout design is a very wise move to minimize the used area and maximize cost effectiveness of using PCB layout.

The project included built-in computer for the users to readily interact to the machine. This minimized the time of transferring data from external source to the motor controller of the machine.

The CNC machine project provided wide array for self-selection of PCB layout designs to be used in Electronics course in Baliuag University. The project already had pre-installed PCB layout designs that were frequently used in stated courses. The users can also easily edit those PCB layout designs for convenience of fitting alternative electrical or electronic components to be used in certain project, laboratory experiment or activity.

The researchers had proven that the machine is ready to be used frequently as they test the machine regularly. The engraver and drill bit were ensured to be sharp for best results.

The CNC machine also offered efficiency with respect to time as traditional etching consumes a lot of time and effort for erasing and drying of the PCB. The machine consumed a couple of minutes depending on the size of the PCB board layout with a maximum size of 8 by 8 inch PCB.

Recommendation

Based on the projects output and capabilities, some improvements are recommended like:

- Changing belt type conveyors to threaded type for better accuracy.
- Using higher torque motors for better accuracy and stability.
- Changing Drill, adding Drill and Engraving bits regularly for better etching, drilling capability.

- Use a better mini PC for better software for more choices and editing capability.
- Provide tinier size drill bit to be used for smaller and complex circuits.

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