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Development of a Desktop PCB Milling Machine

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Abstract: Conventional desktop PCB milling machines cost about $3000 on average, while machines with an onboard liquid crystal display (LCD) for the user interface are nearly non-existent. To address this issue, a desktop PCB milling machine with an embedded LCD display is proposed. Users can save several files on the secure digital (SD) card, tweak the machine on the go, and make the machine work without needing to connect to a computer. This milling machine has three axes and was designed in the same way as a 3D printer. SolidWorks was used to design the machine's structure before being 3D printed while Marlin v2.0.7.2 firmware was used to control the movement. A prototype model was developed to evaluate and verify the design and the findings revealed a 0.2% percentage error between the actual and measured gantry movement.

Keywords: PCB Milling Machine, LCD, SolidWorks, Marlin v2.0.7.2 Firmware

1. Introduction

Due to the rapid growth of technology, the usage and utilization of printed circuit boards (PCBs) in modern consumer products and electronic devices are increasing. PCBs today are rather tiny, multilayer, and far more complex to the extent that they hardly resemble their earliest ancestors [1]. The traditional method of developing PCB boards usually involved a PCB etching machine, which reduces development time since the PCB will go through a few processes before being completed. Furthermore, setting up an etching PCB machine takes a lot of space and it is typically done in a laboratory for safety reasons, which further complicates the printing process. Most laboratories also restrict usage during pandemics and thus most of the users might order custom PCBs from online services which will take a long period and require a high cost.

For this reason, a desktop PCB milling machine was proposed with capabilities to engrave, cut, ream, label, and drill PCB boards. By using a PCB milling machine, users can produce PCBs in their own homes faster, environmentally friendly, and while still maintaining high accuracy. Users can also proceed directly from the design phase to the implementation and testing of their circuit design.

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Meanwhile, if there are any design errors, users can immediately produce a new PCB and run tests again in minutes. This innovation is expected to reduce the time for prototype and product development and users will no longer depend on outsourcing [2].

Hence, the aim of this project is to develop a portable desktop PCB milling machine with an embedded LCD display. To reduce development expenses and complexities, an aftermarket 3D printer motherboard and a touch screen display were used to manage control for the electrical and mechanical components. The motherboard used the latest Marlin v2.0.7.2 firmware which is meant for 3D printing, but the program was modified to cater to the PCB milling requirement. The frame of the machine was designed in SolidWorks and printed out by 3D printing.

2. Materials and Methods

The materials used in this project are based on 3D printer components which basically consist of a motherboard and LCD display to control the machine and a stepper motor to control the gantries movement.

2.1 Materials

Several modules and components are used in this device. Firstly, the microcontroller used in this project is the SKR v1.5 Turbo Mainboard as it comes with a better processor with a frequency 120MHz. There were three NEMA 17 Stepper Motors being used in this project to control the gantries movement of X, Y and Z-axis. The axes were moving in opposite directions at the same time. Besides, the Trinamic TMC2209 motor driver has been used to ensure the engine operated silently and with no discernible stepping movement. The TFT v3.5 LCD Touchscreen Display has also been used to elevate user experience and makes the machine work standalone without having to connect to a computer.

2.2 Methods

Figure 1 shows the functional flowchart of this project. It begins by designing the machine and frame of the PCB milling machine in SolidWorks. After that, the frame is printed by 3D Printer and needs to assemble the development of the PCB milling machine size. After all the process were completed according to the requirement needed, the electronic components which are SKR v1.5 mainboard, Trinamic TMC2209 motor driver and NEMA 17 stepper motors was assembled to test up the project. It had been modified throughout Marlin v2.0 Firmware of designing and the movement of the axis. After that, the machine was manually tested using the TFT35 V3.1 LCD touchscreen display to test for the gantries movement. If the test does not meet the requirement, a troubleshooting process is required.

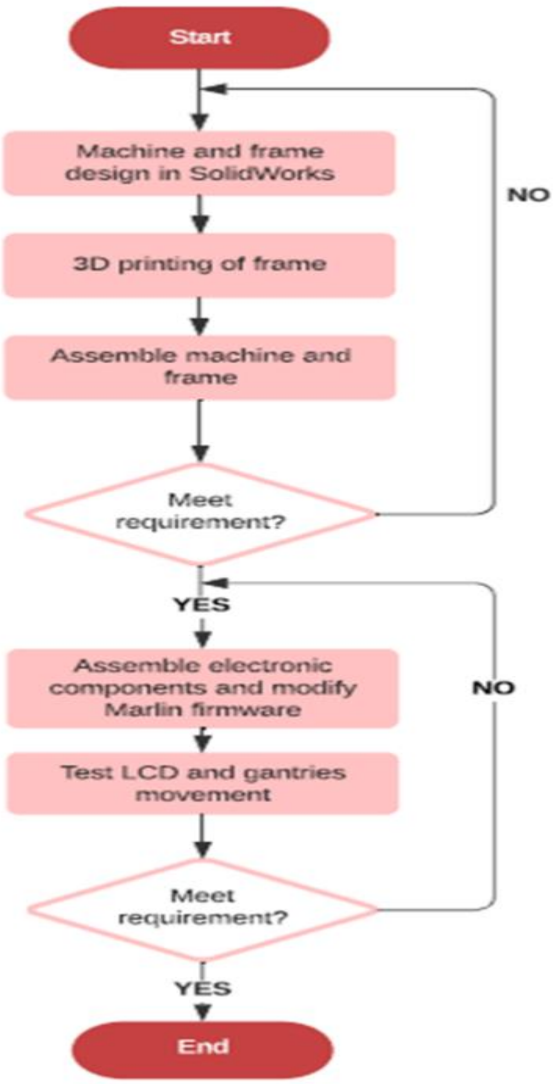

Figure 1: Flowchart of system

Figure 2 shows the machine construction in SolidWorks which has the ability to generate 2D slice data from high-quality solid geometry rather than a tessellated file and save it to the 3MF format [3].

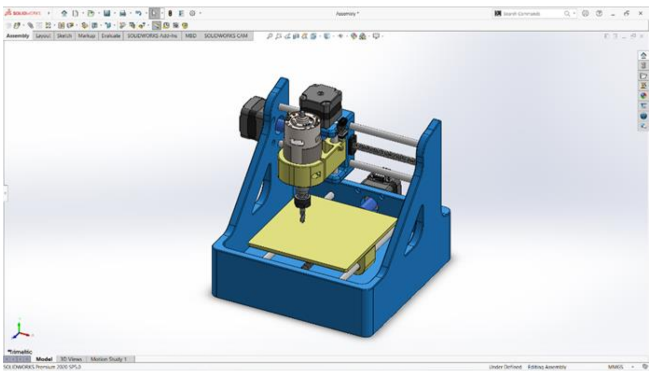

Figure 2: The PCB milling machine designed in SolidWorks

Meanwhile, Figure 3 shows the circuit design of this project which showed the SKR v1.5 Turbo mainboard connected with TFT35 V3.1 LCD Touchscreen display to control the machine movement. There were also 3 stepper motors representing X,Y and Z axis to control the gantries movement.

Furthermore, TMC 2209 motor drivers connected together to ensure the engine operated silently and with no discernible stepping movement. Lastly, the 15V power supply unit is connected to SKR v1.5 Turbo Mainboard to supply the current for the machine movement.

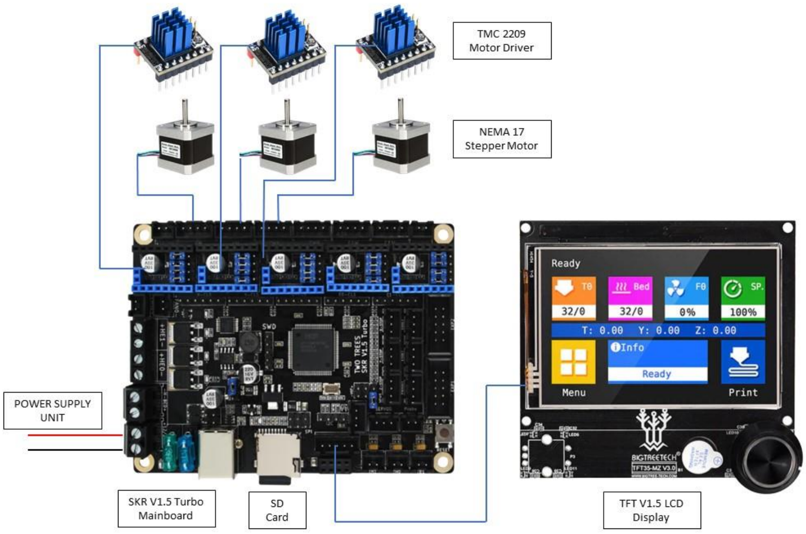

Figure 3: The circuit design of the project

3. Results and Discussion

The primary goal of this project analysis is to compare and contrast multiple functional performances. The most important metrics for this project responded with the accuracy test. Therefore, few factors have been measured in this analysis. Firstly, the sizing and the design helped to smooth out the gantries movement and testing unit procedure to measure the accuracy of project development. Since this project development does not include the spindle head motor thus there is no testing regarding the engraving system test, depth test and cutting test in the testing unit procedure. The primary goal of this project's analysis is to compare and contrast multiple functional performances. The most important metrics for this project will be response time and accuracy. The state of the environment also has a significant role in determining whether or not the system is affected.

3.1 Microstepping

Microstepping reduces the size of small steps to help smooth out the motor's rotation, especially at slow speeds. It can divide a motor's basic step by up to 256 times to make the small steps smaller [4]. Based on this project, a stepper motor converts electronic signals into mechanical movement each time an incoming pulse is applied to the motor. The stepper motor has a 1.8° and 0.9˚step resolution, then in order for the shaft to rotate one complete revolution, in full step operation, the stepper motor would need to receive 200 and 400 pulses. Therefore, 360˚degree per 1.8˚degree is 200 step per rotation meanwhile 360˚degree per 0.9 degree is 400 step per rotation. Hence, the axis per unit configuration is set up 200 steps per rotation for Z-axis and 400 steps per rotation for X-axis and Y-axis. This axis per unit configuration is defined in PlatformIO based on #define DEFAULT_AXIS_STEPS_PER_UNIT on Figure 4, this configuration is about stepper motor configuration for each axis including the extruder, E0. Next, 256 is used to define a microstepping at 1/256. Meanwhile, 14 represented the thread pitch of the leadscrew.

```
/**
 * Default Axis Steps Per Unit (steps/mm)
 * Override with M92
 *                                      X, Y, Z, E0 [, E1[, E2...]]
 */
#define DEFAULT_AXIS_STEPS_PER_UNIT   { 400*256/14, 400*256/14, 200*256/14, 6767.53 }
```

Figure 4: Axis step per unit configuration

3.2 Repeatability testing

After a project is completely completed, its entire performance is judged or reviewed from beginning to end, hence repeatability testing has been made. The marking system test is conducted to measure the accuracy of X-axis and Y-axis in linear position. The X- axis moved right and left meanwhile Z-axis moved back and forth. The test was conducted 5 times for each axis representing the maximum and minimum axis. After that, the average value is calculated to identify the percentage error and the axis accuracy. Figure 5 shows how the marking system test had been made.

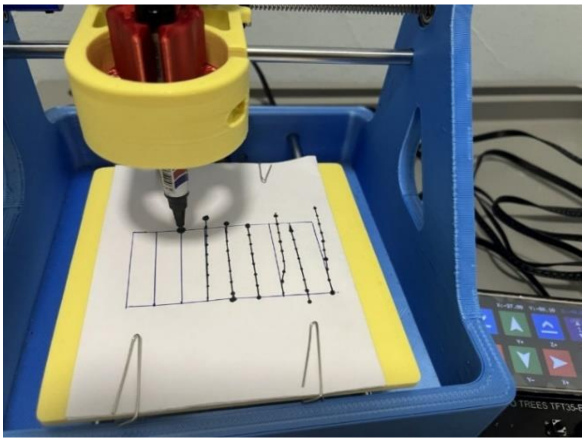

Figure 5: Marking system test conducted on the project

Table 1 shows the measurement accuracy of the axis. The actual value has been set up to 40mm. There were 5 testing to measure the axis value and the percentage error of each test.

Table 1: The measurement of axis

No of testing	Actual value the axis (mm)	Measured value the axis (mm)	Average Value (Actual value – Measured value) / 5 mm	Percentage Error %
1	40	40	0	0
2	40	39	0.2	0.2
3	40	40	0	0
4	40	40	0	0
5	40	40	0	0

The precision of the axis was then computed in this section. Table 2 reveals that most of the tests are accurate, with accuracy rates of up to 99 percent and higher. As a result, it has a lower percentage error and it is appropriate for PCB design that requires a high-precision machine for PCB layout, engraving, and drilling.

Table 2: The measurement accuracy of axis

No of testing	Percentage Error %	Accuracy % (100 % - Percentage error)
1	0	100
2	0.2	99.8
3	0	100
4	0	100
5	0	100

In a summary, in this repeatability test, the measurement of both X and Y axis gave a high accuracy output. Therefore, this PCB milling machine is suitable for engraving, cutting and drilling the PCB layout. Thus, the objective of this project was successfully achieved.

3.3 Overall assembly

The conceptual design of the Development of the Desktop PCB Milling Machine is based on the concept of the gantry moving simultaneously and in opposite directions. To assemble this project, a desktop PCB milling machine had been designed throughout SolidWorks and be printed by 3D Printing using PLA materials. The milling machine had been designed with the maximum size of PCB layout printing area which was 120mm x 120mm. Figure 6 shows a complete design of the product with the Power Supply Unit.

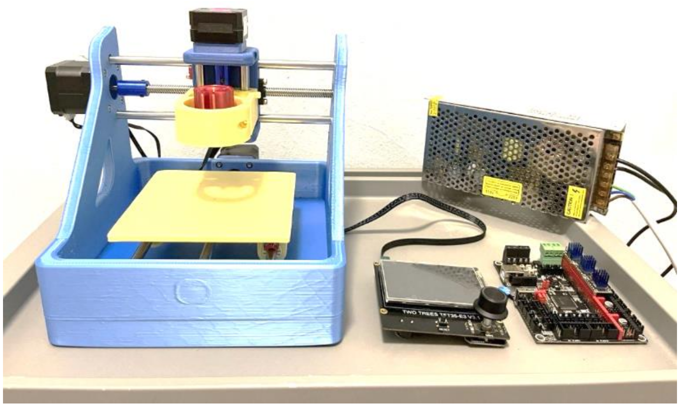

Figure 6: A complete design of the product with the Power Supply Unit

4. Conclusion

Finally, after going through all the problems and troubleshooting of hardware as well as software a mechanical prototype of a desktop PCB milling machine was successfully developed using an SKR V1.5 motherboard combined with NEMA 17 stepper motors. By having an LCD display on the machine, an elevated user experience be achieved where users can save multiple files on the secure digital (SD) card, tune the machine on the go, and make the machine working in standalone without having to connect to a computer. This project can assist society in a variety of ways, such as its long-term durability as this machine can be expected to run for hours without stopping.

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