

Automatic PCB Drilling Machine

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Abstract— This paper describes the design and implementation of an automatic PCB drilling machine that can be used for drilling prototype PCB boards. The Model design is described first, and then the paper moves on to the electronic hardware designing phase where each component is explained and then moves on to explain the program logic written for the automatic PCB drilling machine.

I. INTRODUCTION

Drilling holes in a PCB board that is meant for prototyping can be a complicated task especially when a number of component mounting/soldering holes are involved. The automated process of drilling holes in a Printed Circuit Board (PCB) may not be a new idea as PCB milling machines, see the references [1-8]. Generally, this type of application now is called Computer Numerical Control (CNC) machines. It should have a basic capability of drilling the holes automatically with minimal user inputs. However, using a CNC milling machine for small scale prototyping adds a hefty cost to the project and the average user has be familiar with the operation of the machine [3,4]. A standalone PCB drilling machine is designed and implemented that can be used for drilling holes in PCB prototypes with ease. A PCB drilling machine is build-up of similar components as 3D printers and CNC milling machines. However, the dermal (drill) attached to the PCB drill is specifically modelled for boring holes on Copper Clad boards.

This paper presents the designing and implementation of a Small and affordable automated PCB drilling machine only for the purpose of Drilling holes on PCB. The solution for a drilling machine is proposed as such that it is easy to construct, promotes a user friendly interface and can be easily maintained throughout its life span. The paper generally divides the designing and implementation of the automatic PCB drilling machine in three aspects, firstly the model of the design is discussed with various components, secondly the electronic circuit components are divided and discussed and the final major component discussed is the software programme for the automatic PCB milling machine.

II. PCB DRILLING MACHINE OPERATION

The basic operation of the PCB drilling machine would be to position the drill bit to desired hole position and then to bring down the drill bit to make the hole. The important aspect to be considered would be the torque needed from the Z-axis to force the drill bit through the PCB clad board successfully. Second important aspects to be considered would be the feed

rate of the Z-axis. Too fast feed rate would increases the probability of the drill bit to bend and break. Whereas a slower feed rate would add to the operation time of the machine. To solve the torque requirement for the Z-axis, a servo motor is used. The other two, x and y axis are to be controlled via 1.8degree per step stepper motor.

The third important aspect to consider is the user interface. The following parameters were set for the PCB drilling machine:

- the user would enter the hole positions in form of xy coordinates in millimetres
- a four button user interface: enter button, increment button, decrement button and a button to save the xy positions
- a maximum PCB board size of 3.5 inches or 88mm
- an LCD interface

III. MODEL DESIGN

The PCB drilling machine contains mechanical components that work together to position the drill bit per requirements. To design such a complicated mechatronic system, AutoCAD software is utilised and a model is made to measurements and required specifications. Three basic movements, X-axis, Y-axis and Z-axis are needed to position the drill bit for making holes.

A. X-axis Movement

The X-axis movement consists of a 10 mm full thread rod that is turned by a size 17 number stepper motor. The full thread rod converts the rotational motion into linear motion via two M10 nuts. The M10 nuts are embedded onto the drill table that contains braces for clamping the PCB board in place as shown in Fig. 1. Having sliding clamps on the drill table makes the PCB holder to easily accommodate a number of PCB sizes.

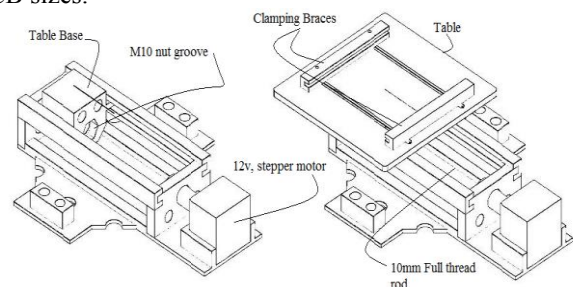


Fig. 1. Components for the X-Axis movement in the drilling machine.

B. Y-axis Movement

The Y-axis movement also consists of a 10mm full thread rod that is turned by a size 17 stepper motor. However, the Y-axis design is completely different from the X-axis as the Y-axis would be responsible for carrying a DC motor drill and a

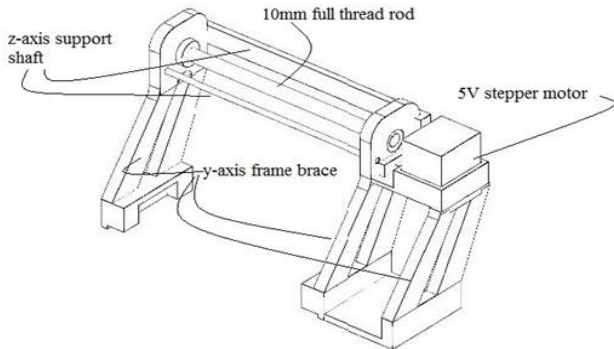


Fig. 2. Components for the Y-Axis movement in the drilling machine.

servo motor as the Z-axis. The part is printed using 3D printer as shown in Fig. 2.

C. Z-axis Movement

The Z-axis movement caters a servo motor that moves the DC motor drill in the vertical direction. The design block is shown in Fig. 3.

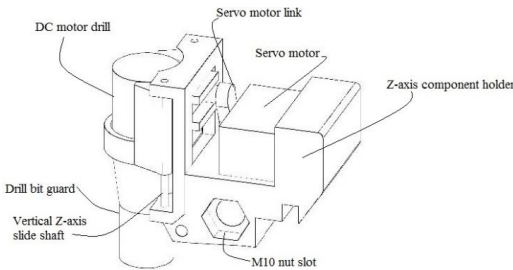


Fig. 3. Z-Axis movement in the drilling machine.

D. The Final Model

The final 3D printed model of the PCB Drilling machine with all the mechanical components fixed is shown in Fig. 4.

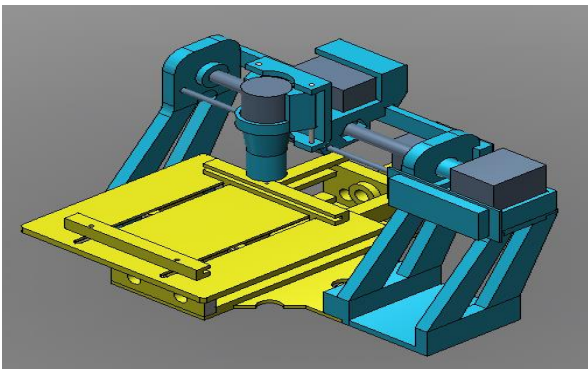


Fig. 4. PCB drilling machine.

IV. X AND Y AXIS STEPPER MOTOR DRIVER

The circuit for the PCB drilling machine is designed to meet the operating functionality of the machine. Firstly the driver circuit for the X and Y axis stepper motor was designed and tested using a temporarily connected PIC18f8722 development board for easy debugging.

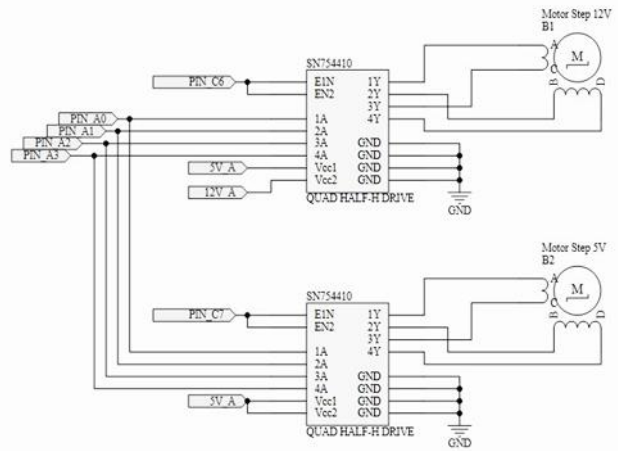


Fig. 5. X and Y axis stepper motor driver circuit.

As shown in Fig. 5, two SN754410 driver IC is used to drive the stepper motors. Both stepper motors are used bipolar configuration and wave drive mode to reduce power consumption. The torque component is not highly required for axis movement operation in the PCB drilling machine.

The two driver ICs share the same data line that is connected to pins A0, A1, A2 and A3 of the microcontroller that provides pulses to the H-Bridge. To select which axis to set, the enable pins of the H-Bridge IC is used. There are instances when both IC are enabled to set the X and Y axis simultaneously and then there are instances whereby only either of the IC is enabled to drive a particular axis. Simultaneous operation of both the axis can be seen when the machine is setting itself at the home position.

The X axis is driven by a 12v 1.8degree step angle stepper motor whereas the Y axis is driven by a 5v 1.8degree step angle stepper motor. This is due to the availability of different size of motors and similar stepper motors could not be obtained.

V. Z AXIS SERVO MOTOR CIRCUIT

The z axis has a 360 degree rotating servo motor that provides more than enough torque for drilling purpose. The difficult part of interfacing a 360 degree rotating servo motor is that there is no specific pulse to guide the servo to rotate a particular angle and keeps rotating depending on the duty of the signal provided. Therefore, two limit switches are used to limit the top and bottom position of the Z axis. Without the limit switch, neither would it be safe to operate the servo motor as the torque build up would damage the servo nor would it be possible to decide if the z axis has travelled to desired location while drilling. The limit switches act as

sensors, telling the position of the axis to the microcontroller. In any servo we need to have one pin to connect to 5V and second to connect ground and third one to give PWM signal for servo control. Amazingly, the servo motor has a small potentiometer that allows the hobbyist to tune the motor. The tuning of servo was also carried out using a temporary circuit connected to PIC18f8722 development board. A PWM signal was provided with an ON time of 2ms. As soon as the signal was seen at the signal pin, the servo spins at a particular direction. Then the potentiometer is slowly adjusted so that the servo stops spinning, if done successfully, then this becomes the boundary signal. Now if a lower ON time signal will rotate the servo shaft in one direction and a higher ON time than 2ms will rotate the servo shaft in another direction.

After tuning, several different signals were experimented with and the appropriate signal was chosen. This phase was important as later the two acquired signal ON time would be used to set the feed rate of the drill or Z axis and then to bring it back up. The feed rate signal chosen had a ON time of 1ms and applied every 500ms for a slow feed rate while the ON time for retracting the drill bit was set to 3ms and applied every 40ms for faster retraction rate.

VI. Z AXIS SERVO MOTOR CIRCUIT

The drill for the machine is a simple DC motor that has enough torque to make hole in the PCB board with a 1/16 size steel drill bit. However, the torque values and ratings of the dc motor were not directly obtained but experimented with using small setup made in the lab. The DC drill was made and connected to a bench power supply. Then voltage of around 6V was applied with a current of 500mA. The drilling phase on PCB was started and slowly the voltage being applied was increased and along with the current being supplied. The final quantity was a 9V max voltage and a current of around 600mA under drilling load.

However, the difficulty with the Drill circuit was the unavailability of a 9V positive voltage regulator. To solve the problem, a 12v regulator was used as a substitute and PWM method was applied to control the Drill motor. A power transistor was used to control the servo motor as shown connection in Fig. 6.

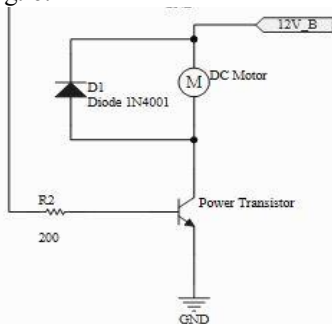


Fig. 6. Dc motor Drill circuit.

As seen in Fig. 6, the NPN power transistor is connected between the DC motor and ground. To operate the power transistor in saturation (as a switch), the 200ohm resistor RB is used, again the value of resistor was obtained using experimental setup and was actually implemented on bread board for testing before the circuit could be finalised. Since the motor is an inductive load comprising of series of coils, to accommodate the back EMF problem a freewheeling diode 1n4001 is used.

VII. LCD DISPLAY

The LCD display circuit is simply the connections between the microcontroller and LCD. Four bit data configuration is used to send data to the LCD and connection diagram is given in Fig. 7.

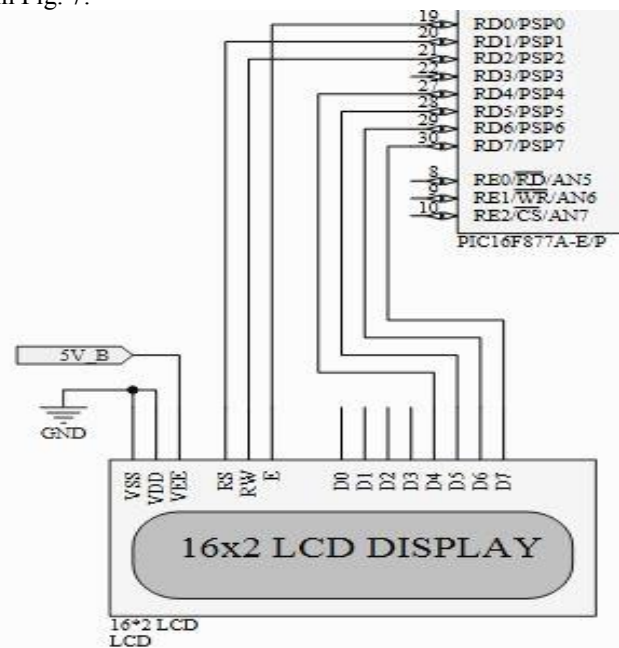


Fig. 7. LCD and microcontroller connection.

VIII. LIMIT SWITCH AND BUTTONS

There are a total of four limit switch sensors being used. As mentioned previously, two limit switches are needed for the Z axis servo motor. Additional two limit switches are needed to limit the X and Y axis positions at the home positions. The maximum of either axis therefore can be limited in the program by means of counting the pulses rather than using two more limit switches. There are four input buttons in the machine. The microcontroller has a total of 8 pull up pins (Port B0-B7) (See Fig. 8). To have a robust detection of button press made and limit switch status, active low input is used. One of the major advantages of detecting active low input over detecting active high input is that the design makes the system immune to noise being detected at the input pins.

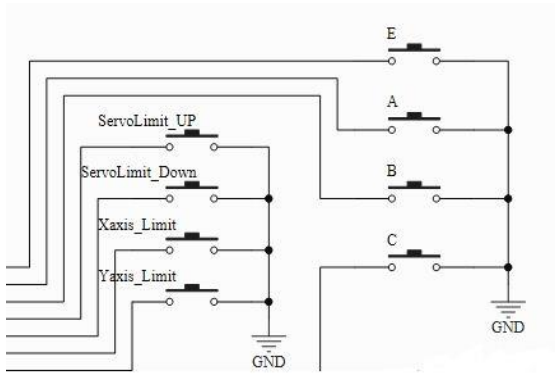


Fig. 8. Limit switches and input button connection.

IX. PIC MICROCONTROLLER 16F877

The brain controlling the sequence of operation being carried out in the drilling machine is PIC16F877 (Fig. 9). The particular PIC was chosen due to its availability and its ability to be used with minimum components on the circuit without carrying along with it the boot loader board.

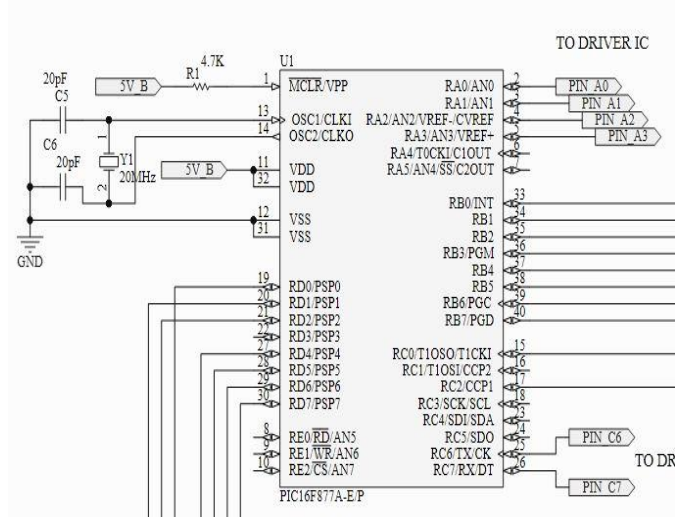


Fig. 9. PIC16F877 necessary components.

The operation of the PIC is set to 20 MHz and the filter capacitors 20pf are used to maintain the operation of the crystal. R1 of 4.7 Kilo ohms is used to pull up the Vpp pin to prevent the PIC from resetting. These are the only necessary components required for PIC operation including the 5V power supply.

X. POWER SUPPLY REGULATORS

There are a total of 4 positive voltage regulators the supply a regulated voltage to various components of the PCB drilling machine.

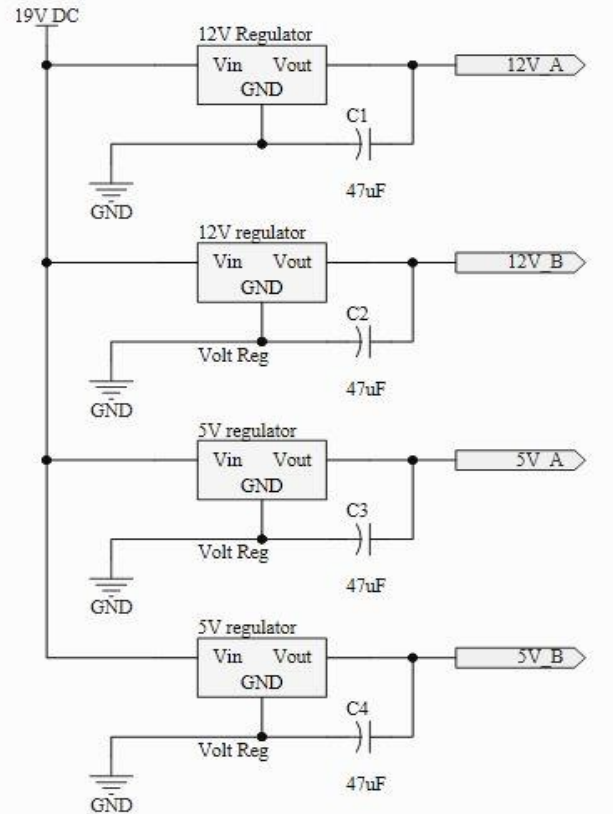


Fig. 10. Voltage regulator circuit.

The individual regulators are rated at 1A max loading and therefore two of each voltage 12v and 5v regulators are used and circuit diagram is shown in Fig. 10. It may be possible to operate the loads altogether with only one of each 12v and 5v regulator. However, the load seen by the regulators would make the regulators heat up quickly or even give up during operation.

Heat sinks are employed on each regulator for heat dissipation to maintain proper operation and prevent deviation of regulated voltage as increase in temperature of the regulators can allow the regulators to cause changes in the output voltages. The good aspect of the regulators used is that they are able to handle up to 30v dc as input without damage as per datasheet. Therefore, a single suitable power converter picked was a laptop charger that provides efficient supply of 19v to the power supply circuit. The 47uf polar capacitors are used to filter possible ripples in the output voltages to make robust outputs.

XI. PROGRAMME LOGIC FLOWCHART

The language used to write the PCB drilling machine program is C. It is much easier when compared to assembly level language and requires less time to write. When the PCB drilling machine is turned on, a "welcome" message is displayed and soon after the program tells user to wait as

internally, the program determines if the drill and the axis's are at home positions or not. The program will not proceed further until the components are sensed to be at home position via limit switches.

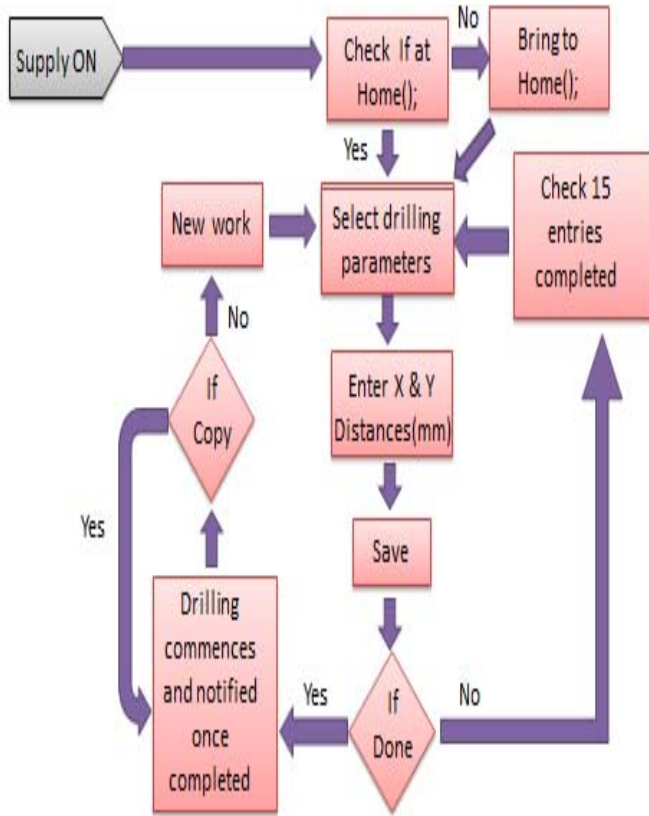


Fig.11. Flow chart of automatic PCB drilling machine.

Fig. 11, shows the flow of program that is running in the microcontroller. As mentioned, an initial check is made to detect if components are at home positions or not, then only if at home position, the program proceeds. A scroll message is displayed showing a quick operation instruction about how to set the drill positions and the button functions.

When enter button is pressed, the user is allowed to set the y axis position and can scroll by pressing the enter button again to set the x axis position. The scrolling button is used to select which axis value to set and the loop continues until the save button 'C' is pressed whereby the location is automatically saved. Then the program informs the user via the LCD display as to the number of space left to save for hole positions. An option is given to user if he/she wants to save another location or is done with the hole positions and wants to proceed with the drilling. If another location is to be saved, then key 'A' is pressed and once again the user is able to set the next hole position. Within the program, the number of space being filled is counted and automatically tells user that a maximum of 15 hole positions have been filled and to press enter button 'E' to proceed with drilling.

However, if the user chooses done option instead of next hole location by pressing button 'B', the program

automatically proceeds with the drilling process. The drilling is done in the order of the positions entered and once done, a user is prompted between two options, either to copy the same hole positions on another board or to enter new hole positions. If copy selection is made via button 'A', then the user is prompted to put a new PCB and press enter button 'E'. Then the copy of hole is made. However, if new hole position is selected via button 'B', the array storing the hole positions are erased and new hole positions can be entered.

XIII. DISCUSSION

The design and implementation has been successfully completed and the operation of automatic PCB drilling machine verified. However, various aspects of the machine can be improved to give more efficient operation. Such as the inclusion of an EEPROM IC that can be interfaced with the microcontroller so that the drilling hole positions are saved and not erased after power OFF. Another enhancement that can be made would be to add a MAX232 IC to enable RS232 communication with the machine via PC. A simple C programme can then be written to send over to the machine the extracted drill hole CNC G-Code and only the hole information is decoded by the automatic PCB drilling machine and make holes respectively. To add on, there are endless possible improvements and ideas that can be integrated with the machine designed and discussed in this paper.

Overall design cost for the prototype is given in the Table I. Overall price for this PCB Drilling machine prototype is very low. It seems that mass production of this prototype can be done even at lower cost. This low cost PCB drilling machine can be very useful for different educational institute for demonstration purpose.

TABLE I. Drilling Machine Part list

Part	Quantity	Price FJD
stepper motor	2	32.11
Servo motor	1	29.96
SN754410 Driver IC	2	5.05
16x2 LCD	1	29.96
PIC16F877	1	21.37
Voltage regulator 5v	2	2.04
Voltage regulator 12v	2	3.22
12V DC motor	1	32.11
Buttons	4	0.75
20MHz Crystal	1	2.04
transistor	1	1.07
SPDT Switch	1	3.22
Capacitors	4	0.97
Limit switch	4	2.02
3D Printed components	10	60
Total		279.53

XIV. CONCLUSION

A low cost automatic PCB drilling machine was developed using basic electronics components. A performance was evaluated for different dimension of boards and location of holes. The user can select the different distances between holes and can be used for same specified inputs for large scale production. A robust performance was achieved for almost 100 operations. There are some scope to improve the present model's features. However, the main objective with small size mechatronics application has been successfully fulfilled.

ACKNOWLEDEMENT

The research team would like to thank the School of Engineering at the Faculty of Science, Technology & Environment at the University of the South Pacific for funding this research project.

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