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Design and Implementation of Low Cost Computer Numerical Control-Printed Circuit Boards Drilling Machine

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Abstract*—Electronic manufacturing sector uses Computer Numerical Control (CNC) machines for drilling holes on Printed Circuit Board (PCB). We designed the frame of our hardware in a way that achieved the aims of this paper. This paper aims at describing the design of a computer numeric control drilling machine. The said machine is designed with a view to keep the cost of the machine at minimum, hence making is suitable for use in small or medium scale industries. Along with the design of the mechanical components, the electronics and the software has also been designed. In this paper we used a C# language to create our software application, which allows the easy integration of input and output functions with any software that we develop in C#. Our CNC machine consists of components like driver, drill, three stepper motors, cables and microcontroller PIC16f877A to control the movement of the machine. The system consists of three main parts: a mechanical setup that can move in X, Y and Z directions, a driving circuitry and a software program that controls overall operation of the whole system. In this initial work, the system is developed such that it produces a trace line on a PCB board and drill holes on two pads at both end of the trace line. We show that our system successfully performs both of the above tasks.

***Index Terms*—Drilling Machine, CNC Machine Design, CNC Graphical User Interface, Low Cost Automation, PIC16f877A Microcontroller.**

I. INTRODUCTION

Computer Numerical Control (CNC) drilling machine plays an important role in today's manufacturing processes. The machines are applicable with procedure to drilling, spreading, weaning and threading with a lot of precise holes. CNC machines have advanced the holes drilling process as this manufacturing process now has been completely automated. CNC drilling machine can be classified as CNC Printed Circuit Board (PCB) drill, CNC vertical drill, CNC deep-hole drill, drilling center and other large CNC drilling machine [1], [2]. This machine is used for drilling holes with numerical control and widely used in hole processing technology for the PCB [3].

Onwubolu et. al. [4] developed a PC-based computer numerical control (CNC) drilling machine. Both the machine and the driving circuitry were built in house. They have used a PC as a separate front-end interface for the drilling machine. The system they had developed integrated several features such as customized machine control unit, enhanced parallel port communication and neural network based optimizer in order to find the best distance optimized sequence of points to be drilled. They have reported successful drilling of PCBs with their system.

A drilling machine is a device for making holes in components. The manually operated type of drilling machine creates problems such as low accuracy, high setup time, low productivity, etc. A CNC machine overcomes all these problems but the main disadvantage of a CNC drilling machine is the high initial cost and requirement of skilled operator for operating the machine. Hence, there arises a need for a low cost CNC machine which can not only drill holes with high accuracy and low machining time but also have low initial cost. The need for skilled operator is eliminated by providing software with a more user friendly graphical user interface.

II. DESIGN CONSIDERATIONS

A. Work Piece Size

As a basis for further development of the drilling machine, the maximum component size (maximum travel along the axis) is selected as:

1. X = 450 mm.
2. Y = 300 mm.
3. Z = 180 mm.

B. Configuration Selection

The different configurations are considered from fabrication point of view, and it is found that the gantry configuration is most suitable because of the following qualities.

1. Provides better rigidity.
2. Better accuracy.
3. Ease of operation and programming.

C. Drilling Machine Components

The drilling machine is divided into three sub systems. These are

1. The mechanical setup.
2. The driving circuitry.
3. The software program.

III. MACHINE DESIGN

The earliest studies in holes drill routing was conducted by Kolahan and Liang [5] in 1996. The researchers suggested the use of Tabu Search Algorithm (TSA) in solving case study, which consists of variable holes sizes. Few years later, the authors proposed an improved version of the TSA in [6] used a TSA approach to minimize the total processing cost for

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hole-making operations. They considered tool travel time, tool switching time and the cutting time and used the TSA to find the solution. This concern for calculation of the minimum tool path length between holes the drilling device has to visit all the lines and holes only once, the machine sequence optimization of the lines is similar to TSP.

So, the distance of the path can fundamentally be calculated using TSP which formula written as in equation (1).

$$M_{total} = \sum_{i=0}^{n}\sum_{j=0}^{n}(|x_i - x_j| + |y_i - y_j|) \times P_{ij} \quad (1)$$

Where n is the number of holes needed. P_{ij} is the decision variable related to the assignment of the drill bit from hole i to j. If movement of the drill bit from hole i to j, thus, $P_{ij} = 1$, otherwise, $P_{ij} = 0$. Coordinates of hole i and j is (x_i , y_i) and (x_j , y_j).

The machines have designed with three movements coordinate, X, Y and Z. Hole position consists of X, Y coordinates, and Z coordinate is a parameter to move the drill machines up and down. The drill is moved horizontally to X, Y coordinates of a hole, moved down in Z direction to make the hole, then withdrawn and translated to another place.

Holes data file supplied and calculated the route with Euclidean TSP by the software to control the drilling machine movement. The electro-mechanical system is responsible for the 3D motion to position the drill, and should be of real industry standard to guarantee the force, torque, precision, and robustness requirements.

A. Frames Sub Assembly

There are four cross section plates welded together to form each of the top and bottom part of the frame. Also other plates are bolted vertically to these portions to form the frame structure. Two beams are placed horizontally along X axis and bolted to the vertical beams to form the guides for the X axis base. As shown in Figure1.

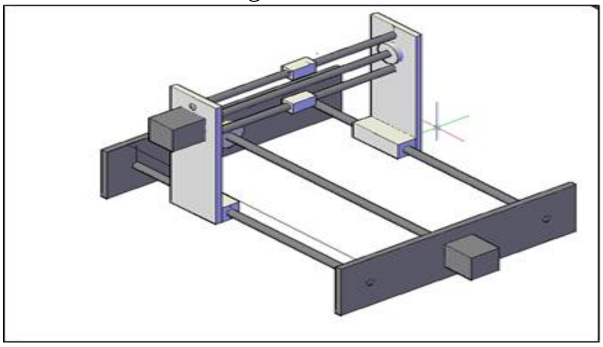

Fig.1: Frame sub assembly

B. X-Axis Sub Assembly

Two bearings are placed on either side of the X axis screw. These bearings are then supported in the bearing seat provided in the side plates. Two guiding rods are fit between the two side plates. Each of the side plates has two M12 taps at the bottom to screw them to the frame. The motor is screwed to the motor support plate which is in turn attached to the guide rods. The shaft of the motor has a radial hole which is used to couple the motor to the screw.

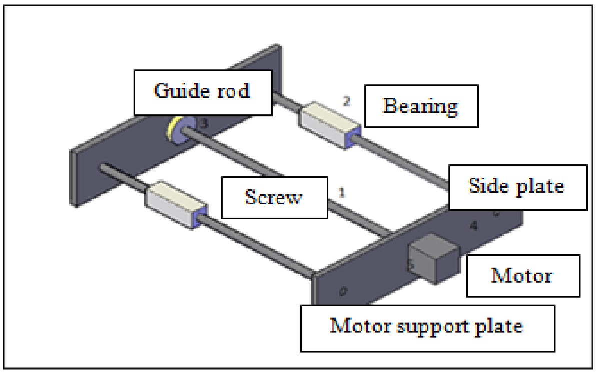

Fig. 2: X-axis sub assembly

C. Y-Axis Sub Assembly

The Y axis is similar in construction to the X axis sub assembly. The mid plate has two M12 taps for the attachment of Z axis sub assembly.

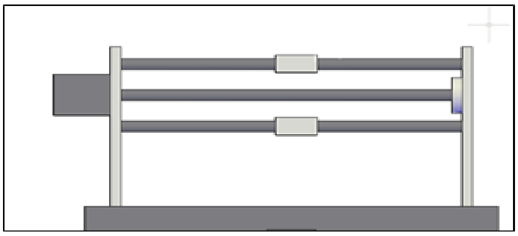

Fig. 3: Y-axis sub assembly

D. Z-Axis Sub Assembly

The Z axis is also similar in construction to the X axis sub assembly. The mid plate has a provision for the attachment of the drill motor. This feature gives our machine the possibility of changing the Feather drilling and used for multiple purposes.

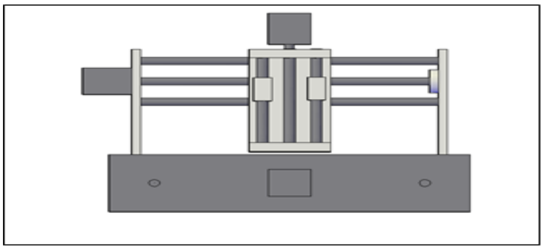

Fig. 4: Z-axis sub assembly

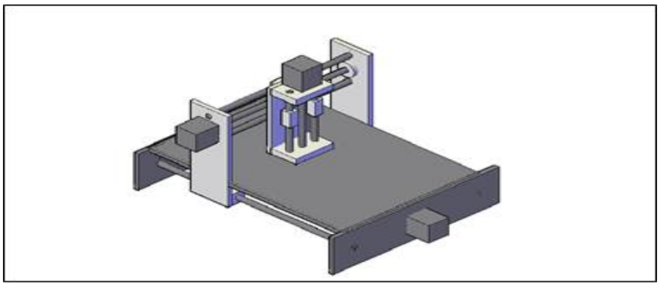

Fig. 5: Final assembly

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IV. METHOD

This paper demonstrates hardware and software implementation of a PCB machine that is able to draw trace lines and drill holes to designated places on a board. The system consists of a mechanical setup of that can move in X, Y and Z directions, a computer, a driving circuit and a software program. The driving circuit is developed to control the mechanical setup as well as to communicate with the computer. The software program is developed to control overall operation of the machine. In this initial work, we have demonstrated that the machine can produce a trace line on a single layer PCB board and drill holes on two pads that are on both ends of the trace line. We continue studying to enhance different aspects of working of the system as they will be demonstrated in our future works.

The mechanical setup has a flat layer on which PCB is put on it to be processed. Above the flat layer, there is a drill that can move along X, Y axis. The drill can also move up and down for a specified amount of distance. There is a bit connected to the bottom of the drill. Both trace lines and holes are produced using this bit. To produce a trace line on a single layer PCB, we first adjust the drill such that it only moves down to 0.5 mm below of the surface of the board. We then send start coordinate of a trace line to the PIC. Upon receiving this signal, PIC moves the drill to the location of starting coordinate. During this movement, the drill is at up position. When the drill receives the specified location, PCB machine puts the drill at down position, starts drilling and move continuously according to the coordinates sent from computer. The coordinates have to belong to edges of a trace line that is to be drawn. During this process, the drill bit carves the copper layer on the surface of the PCB continuously as deep as 0.5 mm. Hence the trace line is separated from the remaining part of the copper on the PCB when the process is completed.

In order to drill a hole on the same PCB, we let the machine to finish up the tracing, and then readjust the drill so that it moves down approximately 2 mm below of the surface of PCB. After that, we specify coordinates and let the drill go to those positions and perform drilling one at a time.

V. DRIVINING CIRCUITRY

In this study we drill the wires first, and then we drill the holes at the beginning and the end of wires. The previous study drills the holes first, and then it drills the wires. A feasible solution in PCB wires drilling is simply a complete sequence such that all wires must be visited and each wire is visited once only.

We have designed and developed a driving circuit given in the Figure 6 in order to operate the PCB machine.

The driving circuitry is developed using a PIC16f877A microcontroller. It controls and runs specific functions of the machine such as running step motors to move the machine in X, Y axis, running the drill and enabling or disabling an actuator that moves the drill up or down, it also communicates with computer port. The computer is used to perform specific tasks such as sending coordinates of trace lines and pads to the driving circuitry and receiving acknowledge signals from the PIC. A program is written in C# to achieve overall control of the machine and to perform data communication between computer and driving circuitry. Coordinates of trace lines and pads are kept in a file in the computer. It is also a job of the C# program to open this file, read coordinates and send them to the PIC in order to have the PCB machine to perform desired tasks.

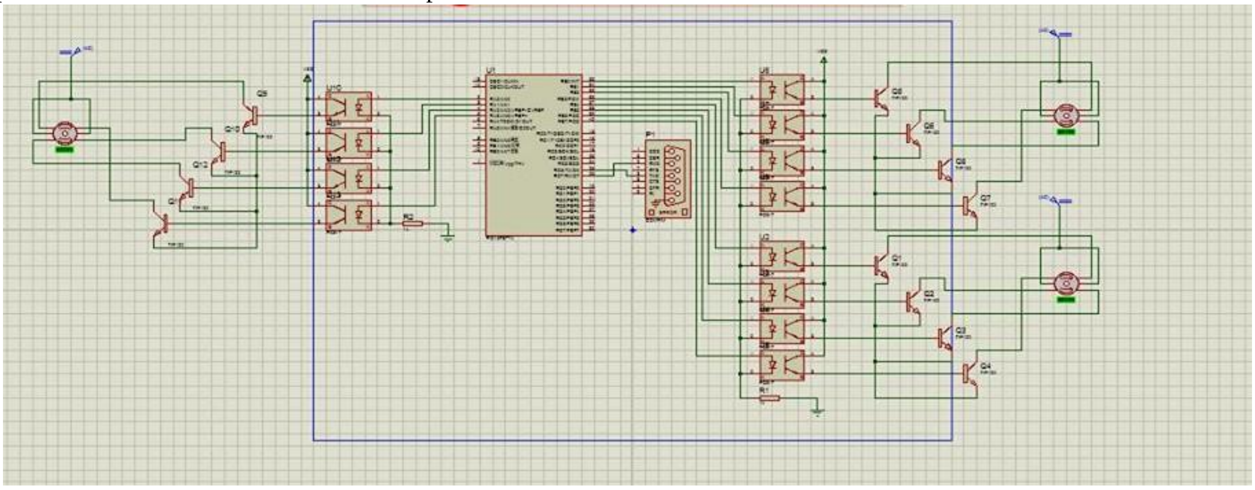

Fig.6: The schematic of the driving circuitry

VI. SOFTWARE DESCRIPTION AND RESULTS

It was necessary to build strong software which operates the hardware and computer elements. There are two separate programs running in parallel in order to operate the PCB machine. The first program runs in the PIC16f877A, it is written in assembly language of the PIC and performs the actual step motor driving, runs the drill, accomplishes actuator on/off operations and reads data from sensors placed on the PCB machines.

The second program runs in the computer and controls overall operation of the whole process, it is written in C#; it

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reads coordinates from a file, sends them to the PCB machine to be processed and receives data from driving circuitry. It also determines on/off status of the drill, enable/disable status of the drill actuator and sends appropriate signals to PIC to implement these statuses.

We built a software that help the user to draw his own circuit accurately and easily, and then press on button "start" to send it to the hardware to have his own PCB. The program is written in C# and the simulation is performed 50 times on a laptop that is equipped with 2.20 GHz Intel(R) Core(TM) 2 Duo T6600 processor with 4 GB RAM. The CNC PCB machine that we have developed performed drawing of a trace line and drilled holes on both end of the trace line successfully. The following figures our software application interfaces:

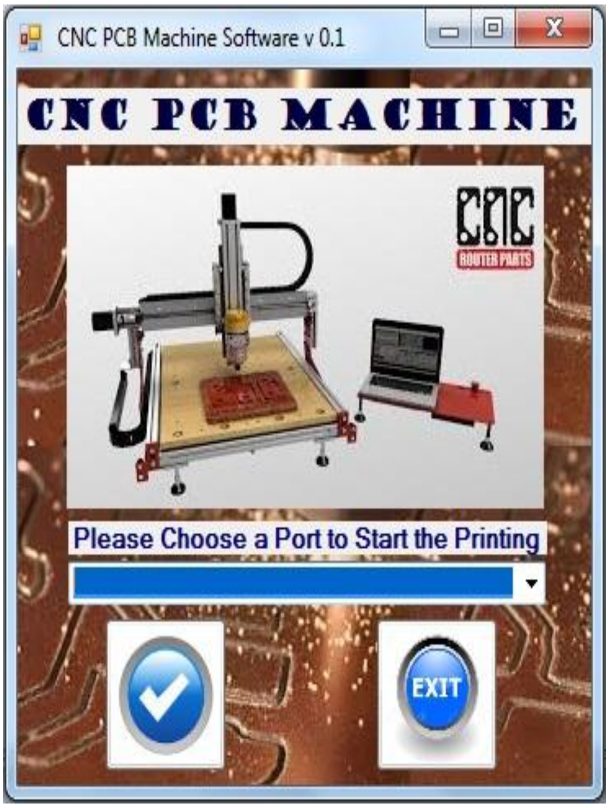

Fig.7: Start dialog interface

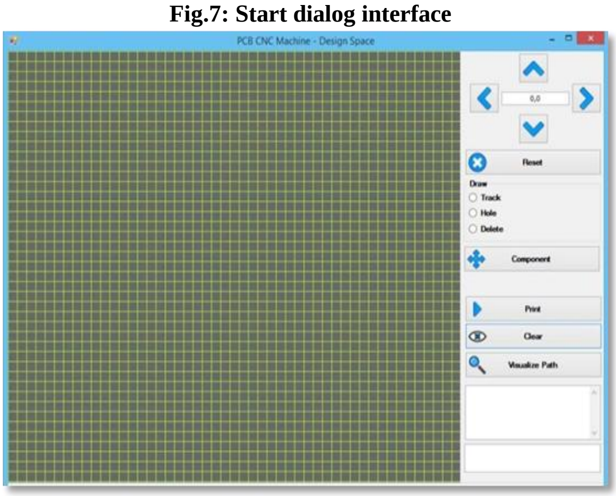

Fig.8: Main interface

The following figure shows how the drill moves along the lines:

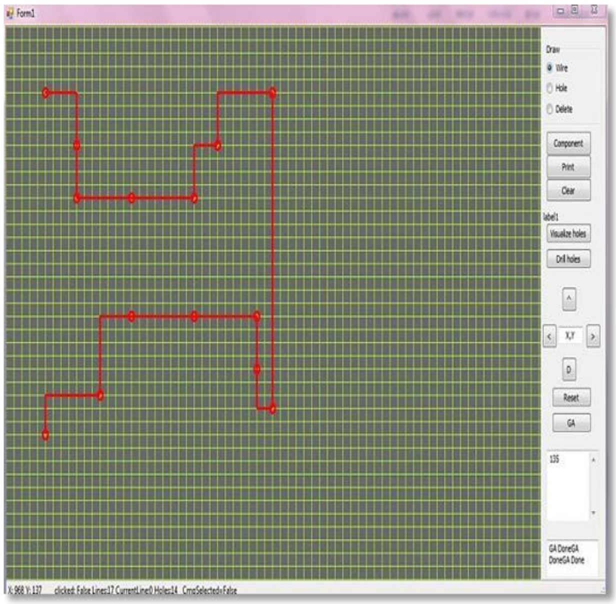

Fig. 9: Path optimization interface

VII. DISCUSSION AND FUTURE WORKS

The development of CNC PCB drilling machine have been done. In its development, the cost incurred is very competitive and relatively cheap compared with the drilling machines available on the market. Several tests must be conducted to adjust the appropriate parameter such as time delay or motor rotation speed for the optimal work. In our future works, we will continue to enhance different aspect of the PCB machine in order to have it perform line tracing and hole drilling of a complete circuit schematic on a PCB.

VIII. CONCLUSION

In this paper, the proposed CNC PCB drilling machine is equipped with three dimensional movements and considered to produce good precision accuracy for a competitive development cost comparing with another machine products manufactured by other machines which is that are not accurate, especially in drilling holes or trace line and with high cost material that is used in design.

In this study, we have designed and developed a PCB machine that is able to draw trace lines and drill holes on a single layer PCB board. We have tested our system and showed that the PCB machine successfully draw a trace line and drilled holes on both end of the line.

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