CNC PCB DRILLING MACHINE USING NOVEL NATURAL APPROACH TO EUCLIDEAN TSP

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Abstract— **Nowadays, many industries use the Computerized Numerical Control (CNC) for Printed Circuit Board (PCB) drilling machines in industrial operations. It takes a long time to find optimal tour for large number of nodes (up to thousands). To achieve more effective results, optimization systems approach is required to be equipped in drilling machine. Euclidean Traveling Salesman Problem (TSP) is one of optimization method that gives fast near optimal solution for the drilling machine movement using novel friendly techniques. This paper describes the development of that CNC PCB drilling machine with novel approach to Euclidean TSP. This design can be widely applied to various CNC PCB drilling machines in small and medium scale manufacturing industries.**

Keywords: Computerized Numerical Control, Drilling machine, Printed Cicuit Board, Travelling Salesman Problem.

I. INTRODUCTION

Computerized 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 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 use for drilling holes with numerical control and widely use in hole processing technology for the PCB [3].

There are two types of CNC drilling machines available on the market, automatically by the Personal Computer (PC)-based controlled and semi-automatic machines. PC based controlled machine usually provides software to create work order for CNC drilling machine and also provide interface in CAD software. Mostly, disadvantage of these machines is not applied optimum tour method for drilling. Optimum tour may use Traveling Salesman Problem.

Recently research regarding development natural approach to Euclidean TSP is in progress to produce fast algorithm. This approach will result near optimal solution compare to best known solution and the approach shall readable. Preliminary result of this project has done and the result is promising to apply because error average less than 10% compare to best known solution.

Application of TSP to CNC problem will increase optimality machine usage and consequently give higher efficiency result. Mostly CNC machine use brute force method to drill PCB. This is our motivation to build CNC machine for drill PCB and controlled by PC using TSP.

To build this CNC machine, several things have to be considered which are to design a framework of CNC drilling machine, to create a communication protocol between PC and electronic devices using a microcontroller programming, and to develop methods of Euclidean TSP using C++ Programming and applied to the drilling machine system.

II. RELATED WORKS

The TSP naturally arises as a sub problem in many transportation, industries and logistics applications. The TSP has caught much attention of mathematics and computer scientist specifically because it is easy to describe but difficult to solve. Traditionally, a traveling salesman wants to visit all cities without repeating any in while the edges are roads connecting the cities. Weight on the edges indicate the time or distance to travel between cities.

The symmetric TSP, in this case, the traveling costs are presumably symmetric in the sense that traveling form node A to node B just as much as traveling from B to A. This problem is special case with $m_0 = \frac{n(n-1)}{2}$ edges.

Most algorithms for the TSP so far have shown an exponential growth in run time as the number of nodes n on the tour increases. The challenge here is to come out with a standard algorithm that will always produce near optimal tour within limited computational processing. This work applies a novel approach of Euclidean TSP by [5] that has given the solution practically within 10% of known optimal solution.

III. MACHINE DESIGN

The machines have designed with three movements coordinate, X, Y and Z as shows in Fig. 1. 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

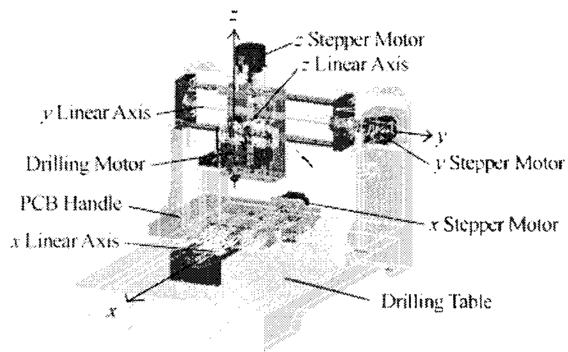

Figure 1. CNC PCB Drilling Machine Design.

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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.

In building this CNC machine, some components needed are classified as follows:

1. Mechanical Component: Steel, Wood, Nut and Bolt
2. Electronics Component: Stepper Motor, Microprocessor, Microcontroller kit and Drilling Motor.
3. Central processing component: Computer, Monitor, Power Supply, Inputs Devise, C++ Programming Software and PCB Drawing Software.

IV. IMPLEMENTATION

The implementation of CNC drilling machine is shows in Fig. 2 below. There are ten important parts in the implementation of this CNC drilling machine. Those parts are described in each section as follows:

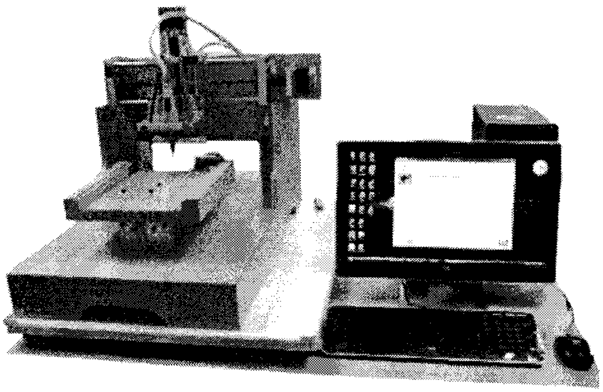


Figure 2. CNC PCB Drilling Prototype Machine.

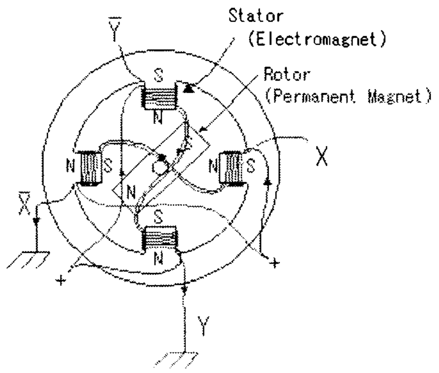


Figure 3. Stepper Motor Control System.

A. Stepper Motor

A stepper motor (or stepping motor) transforms applied voltage pulses into discrete motions called steps. It allows precise control of position and speed without, generally, the need of feedback. This reduces the complexity of the control. Fig. 3 describes a simplified stepper motor – control system. The stator windings are excited according to groups which are called phases. Motors can be of 1, 2, 3, 4, or 6 phases. The number of pole pairs determines the rotation angle for each step or the number of steps for each revolution. Depending on the excitation to motor phases, the motor will operate in one these 3 modes: Full stepping, Half stepping, and Micro stepping. The rotation director is decided by the order of winding excitation.

The stepper motors have been selected with the 5-phase Vexta pk 566-NAP, Frame size 60 mm, Case Length 6, Standard type, Single shaft, Photo coupler input as shows in Fig. 4.

There are some important specifications contained in this stepper motor. Those are:

1. Max holding torque 0.83 Nm
2. Rotor inertia 280.e-07 kgm-2
3. Supply voltage 24 VDC
4. Basic step angle 0.72
5. Mass of motor 0.8 kg

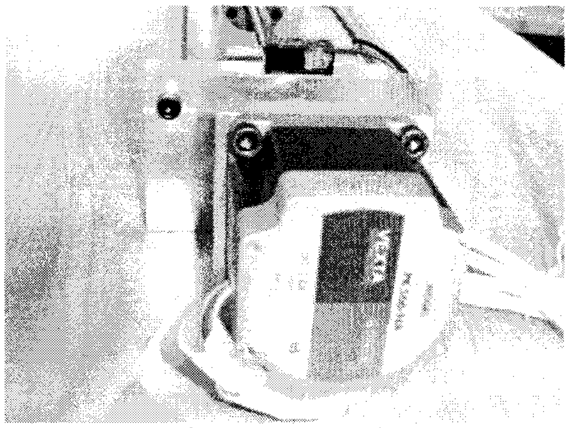


Figure 4. *x*-Stepper Motor Vexta pk 566-NAP.

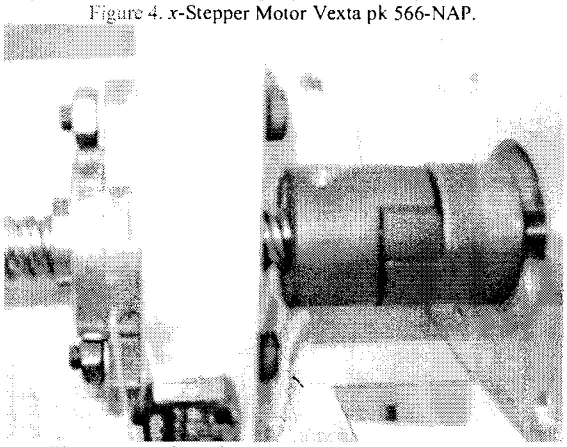


Figure 5. Jaw Coupling compensates linear offset of the axes.

B. Jaw Coupling

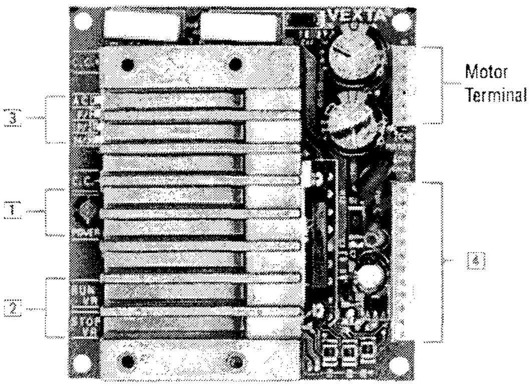
The coupling between motor axis and load has a strong impact on the operation of the motor and efficiency of the system. This machine use anti-twisting jaw coupling for high resolution positioning systems as shown in Fig. 5. When the precision requirement is not so severe, flexible coupling is acceptable, with an advantage in that it can compensate the linear offset of the axes.

C. Power Drive

Power drive is a power electronic circuit to supply switching currents to motor windings. Power drive Vexta EIC 4011 has been used to move every stepped motor in X, Y and Z axes shown in Fig. 6.

D. Electro Mechanical Positioning Axes

An axe converts rotational motion of motor into linear translation. The axes use internal spindle and ball bearings, and transfer internal linear motion to an outside slide which moves along a rigid guide. The axes can be placed at any direction, and can operate in sliding mode (load presses onto slide) or yoke mode (load pulls on slide). Three axes have been used to convert every stepper motor rotation into X, Y and Z linear directions. Every one round (360°) of stepper motor rotate with 500 pulses, the axes will move 8 mm. This makes the machine have a good precision with 0.016 mm/pulse.



1. Signal Motor Display
2. Current Adjustment Potentiometer
3. Function Select Switches
4. Inputs/Outputs signal

Figure 6. Power drive Vexta EIC 4011.

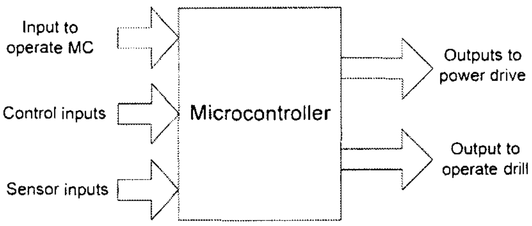


Figure 7. Microcontroller Inputs Outputs.

E. Controller

In this machine, Microcontroller ATmega8535 of ATMEL has been used [6]. The ATmega8535 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing instructions in a single clock cycle, the ATmega8535 achieves throughputs approaching 1 MIPS per MHz allowing the system designed to optimize power consumption versus processing speed. Fig. 7 shows the microcontroller and five signal groups:

1. Inputs to operate the microcontroller.
2. Control inputs.
3. Inputs from sensors: Each X, Y, Z linear axis is equipped with two magnetic proximity switches.
4. Output to power drive.
5. Output control to drill.

F. Drilling Motor

The motor as shows in Fig. 8 is also a very important part of the whole system. It must satisfy the requirements such as: high power, strong starting torque, high revolving speed (e.g. 10,000 revolutions/minute). The motor and bit axes must be on the same vertical direction.

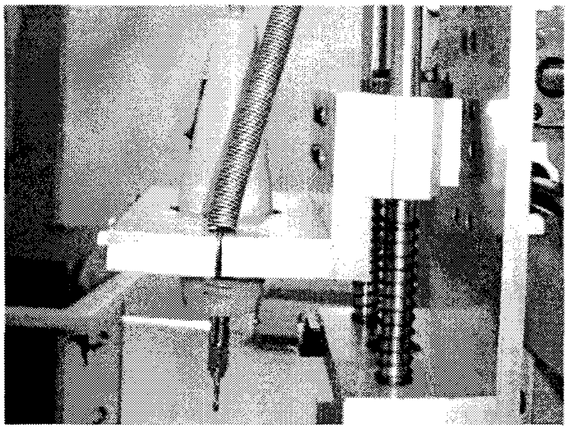


Figure 8. Drilling Motor of Prototype Machine.

TABLE I. THE POWER SOURCE

No	Electronic Devices	Ampere	Voltage
1	The Power Supply	10 A	325 V
2	The 3 Stepper Motor	2.1 A	24 V ± 10 %
3	The Relay	300 mA	12 V
4	The Drilling Motor	1A	12 V
5	The Microcontroller	1A	5 V

G. Stabilized Power Supply

Stabilized power supply is needed to supply constant voltage to every electronic device used. This machine use the Solomon power supply type S-125-24 as shows in Table I.

H. CNC System

The automatic drilling machine can be configured with a CNC system. In CNC system the computer directly controls the drilling machine and receives feedbacks from it. The PCB file from computer is converted to holes data file which is then converted to the form of data appropriate for the microcontroller (MC). These data are uploaded into MC flash ROM via serial port. Upon receiving this data, the MC moves the drill to the position and then drills it. After finishing one hole, the MC waiting the PC for the next coordinates.

To control the stepper motor, the power drive has to generate pulse. From the pre experiments, the optimal delay must be calculated. Shorter delay makes the lost pulse, while longer delay makes the system slow.

The MC also has ready to get feedback from the limit switch when rotating stepper motor. This system guarantees the drill will not work over from track.

The control of the drilling machine is from the computer. When the PCB pattern wants to change, the new PCB file is uploaded to the flash ROM again from computer. Fig. 9 summarizes this CNC system. The computer displays X-Y coordinates of the drill and several other operation states.

I. Micro Controller Programming

Microcontroller programming generates the protocol to receive the output from the C++ program in order to make an action to move the machine. In this machine microcontroller, the Code Vision AVR software has been used. Code Vision AVR is a C cross-compiler, Integrated Development Environment and Automatic Program designed for the Atmel AVR family of microcontrollers.

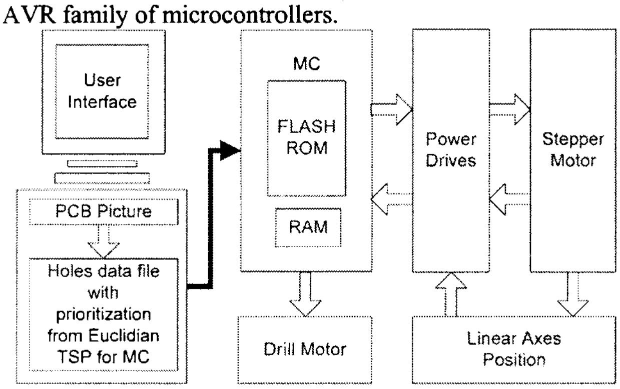


Figure 9. A framework of CNC System.

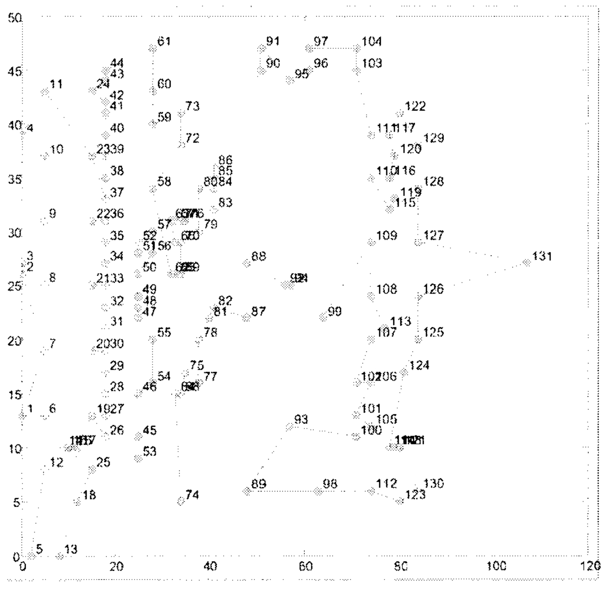


Figure 10. A near optimal ETSP Solution on map xqf131 from TSPLIB.

J. Euclidean TSP Programming

To construct the Euclidean TSP program, the C++ programming language has been used. The C++ implements the methodology to find the global tour with Euclidean TSP. There are several scripts to be produce in this study such as: non edge crossing scripts in planar graph; scripts to generate clusters and able to handle large size cluster; scripts to determine incoming and outgoing vertex to form Hamilton path; Hamilton path scripts by involved incoming and outgoing vertex as start and end point of Hamilton path and produce inter cluster connection scripts to find global tour.

In example, Fig. 10 shows the global tour of map xqf131 from http://www.tsp.gatech.edu/vlsi/xqf131.tsp using the Novel Natural Approach Euclidean TSP program. It has obtained the near optimal result of 581 unit distance. For comparison study, TSPLIB result has shown in Fig. 11 with 564 unit distance of global tour. If the result is compared, the TSP program has excess 3.05% than the result of in TSPLIB. This result is good as the TSP program that has evolved recently.

V. 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. Now, the machine is used for preliminary experiment by drilling the PCB with current Euclidean TSP program. Several tests must be conducted to adjust the appropriate parameter such as time delay or motor rotation speed for the optimal work. New Euclidean TSP methods also are analyzed to embed in the machine. The current issues being analyze are by changing the clustering techniques in current Euclidean TSP method with Hierarchical Clustering method [7] or Least Action Principle method [8]. Future work has been proposed to embed this machine with Computer Vision technology base on the research work by [9].

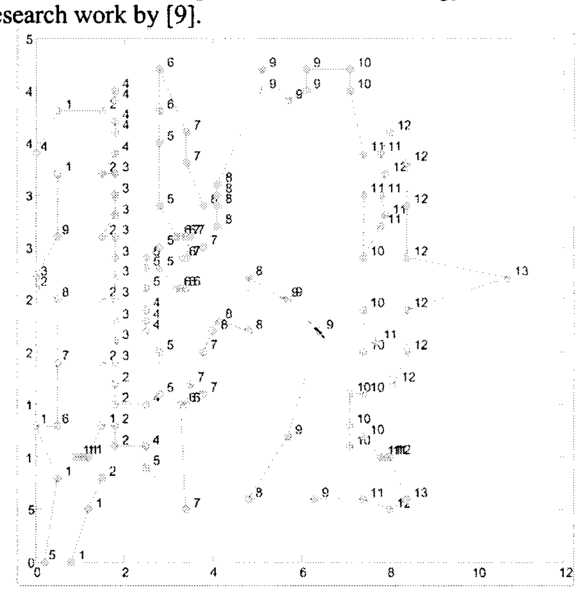


Figure 11. The best solution from Concorde on map xqf131.

VI. CONCLUSION

The CNC PCB drilling machine is equipped with three dimensional movements and considered to produce good precision accuracy for a competitive development cost. This machine has been equipped with a novel approach of Euclidean TSP and integrated with Atmel code vision programming for protocol input output data. The design approach gives promising fast near optimal solution in total tour traveling time and total distance on the PCB with the error average less than 10% compare to best known solution. This design could be widely applied to various CNC PCB drilling machines in small and medium scale manufacturing industries. However, there are still some refinements and improvements need to be done in this machine concept design and in applying Euclidean TSP system to get better solution and functionality.

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