# A Method to Improve Routing and Determining the Shortest Traveling Pathway between PADs in the Automatic Drilling of PCBs Based on Genetic Algorithm

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## Abstract

Automatic drills are widely used in the process of manufacturing printed circuit boards. After a circuit is designed using very advanced softwares, the pins for different components and the nodes through which the layers are connected are rigorously drilled by an automatic drill. At the present paper, a study is done on the function of the automatic drills of printed circuit boards and the difficulties brought about by issues like the sequence of drilling, the functioning time of the device, the device depreciation to optimize the total pathway of the head rail, and the response of the head rail along with tracing the head rail is being studied analytically. The effectiveness of the proposed method is demonstrated on 100 node test pattern through Absolute Error (AE), Mean Square Error (MSE), Mean Percentage of Absolute Error (MPAE) and Mean Regulation (MR%) performance indices. The result evaluation shows that the proposed algorithm achieves good result performance. Moreover, this newly developed strategy has a simple structures provide less depreciation, arisen in the pace of whole system and a reduction in the error of head displacement, which can be useful for the traveling pathway between PADs in the automatic drilling of printed circuit boards.

**Keywords:** Genetic algorithm, PCB Auto Drill, Routing pathway

## 1. Introduction

At industry, for the design and manufacturing of the printed circuit boards, the components are first designed and installed by a PCB Design softwares. These softwares export several output files to be used by different devices. The files include a Pad_list (list of (x,y) coordinates of component pins), Via (place of connection of layers together), Component_List (list of components for assembling machines), soldering masks (mask for soldering guide, etc. Drilling the printed circuit boards is a part of manufacturing electronic boards that is done by automatic drilling devices [1-2]. This device operates on the x-y axes horizontally and vertically, on the plane of the printed circuit board. There is also a depth-oriented movement along the z-axis through which the drilled is lowered to punch the printed circuit fiber. The motion of the head-rail along the three axes is controlled by the step-wise motors. These devices receive the pad-list from a PCB designing software and guide the drill through the specified coordinates of the pins and the connection nodes to punch the pad [3]. The head-rails at these devices usually move following an unsorted list of the software output which requires a long pathway. This long pathway needs more time to be completed and effects sooner device so depreciation and the systematic errors are aggravated. It is like as a Traveling Salesman Problem (TSP) [4-5]. Thus it is important to minimize the total pathway. There are several methods to minimizing the total pathway which are x-then-y method, Snakelike method, the minimum distance method [1-2].

The sorting done with the x then y method is a simple and suitable procedure to enhance the pathway. However, it is still necessary that one find the corresponding y coordinate of each step on the x axis and cross that. That is why the pathway would be a zigzag and long one. Using the snakelike method, the extent of vibrations involved is reduced dramatically. Nevertheless, there will be blind nodes. Therefore, the methods aforesaid can not be reliable enough to fulfill a suitable level of efficiency at the system. To choose the best pathway, all the possible arrangements of nodes, that is, *n!* possible choices for the n nodes available should be considered which leads to a very tedious and time-consuming operation and process specific. Thus, optimization of traveling pathway is an important and essential step to word the design of printed circuit boards. For this reason and to overcome this draw back a genetic algorithm (GA) is being used for minimize the total pathway [6]. To illustrate the effectiveness of the proposed method a 100-node component is considered as a test pattern. The results of proposed genetic algorithms based traveling pathway (GATP) are compared with traditional methods through some performance indices. The performance indices are chosen as Absolute Error (AE), Mean Square Error (MSE), Mean Percentage of Absolute Error (MPAE), and Mean Regulation (MR%). This simulation results show that proposed method not only achieve good result performance, but also it is superior to other classical methods. Moreover the pathway is shorter, the device deprecation and the total functional time will be minimized. Thus, it is recommended to minimize traveling pathway in the automatic drilling of printed circuit boards.

## 2. The Structure of the PCB Automatic drill

A scheme of an automatic drill is shown in fig 1. It is seen that the device operates on the two x and y axes which are orthogonal and displaced by the step-motors along the axes. With a computer command sent to the x motor and the steps being declared, the motor at this axis rotates to the extent commanded and leads the head-rail to the desired place on the x axis. The same operation is carried out for the y axis. The head-rail starts the displacements exactly on a node first drilled and calibrated as the origin (0,0) with respect to the offset node. When guided to the pad area, the head-rail is lowered by the z motor and having completed the drilling, the head rises up to be displaced on the x-y direction heading the other pins. The control board of the device is composed of the step-motor devices and motion censors (linear motion decoder). Some devices have film-encoders on the pathway which alert the command circuit with sending feedbacks to check the sound performance of the motor. In such devices, the servo-motors are mainly used in lieu of the step-motors [2]. The displacement of the automatic head-rail from one node to another requires a movement along the x-y axes. The PCB design software guides the head-rail through the pathway with providing the coordinates. The more exactly the next node is selected, the shorter will be the pathway, that is, less depreciation of the device, less time required and regarding a drop in the number of steps or the step motions of the step-motor, the overall system will be more accurate.

## 3. The proposed algorithm

The PCB designing application softwares, offer the nodal coordinates on the pad which are the pins of the components to be installed. The coordinates may be assigned for a via whose order is the same as designed, that is, how the circuit designer arranges the components on the PCB according to which the pads are listed and fed in to other devices. Therefore, with the same order of the pads, the same old long pathway will be followed.

### 3.1. Sorting through the x-then-y method

Using the x-then-y method, the coordinates of every node is evaluated with respect to an offset node and the coordinates are sorted with sorting algorithms such as Selection, Merge, Quick-sort or any other sorting

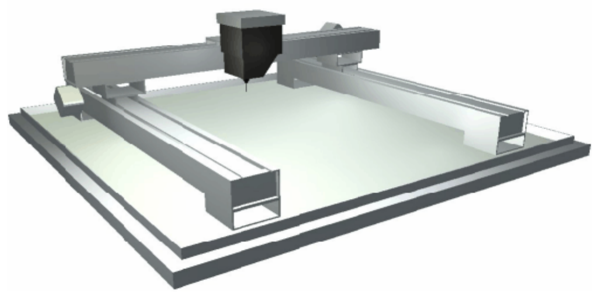

Fig 1: The scheme of the automatic drill.

algorithm on the x axis and the y coordinates corresponding to the x ones are displaced based on

$$\text{If } (x_i > x_j) \text{ then exchange } (P_i, P_j) \tag{1}$$

The relationship above Pi(xi,yi) and Pj(xj,yj) are two separate nodes of the list being discussed.

### 3.2. Snakelike sorting

Using this method, the x axis should be divided into n sections. The axes are sorted y-then-x and x-then-y alternately. The ascending-descending strategy is carried out at the other axes as well. As the motion step x is divided into n sections, the zigzag pathway is 1/n and the leaps (jumps) decease likewise. Great care should be taken in the choice of ‘n’ which must not exceed a limit and if it does, it will result in a local optimization.

### 3.3. Sorting with the minimum distance method

The operation begins with drilling a (0,0) offset point. The distance between any node n relative to an existing node r is calculated using equation 2 and compared to the previous values to find the minimum value - the shortest path to the next node - and list it. The node assumed is the node r and the nearest node to r is to be found:

$$D = \sqrt{(x_r - x_n)^2 + (y_r - y_n)^2} \tag{2}$$

Using this method, the system is accelerated considerably and the pathway shrinks.

Although the methods discussed above offer a relative improvement, they are not able to minimize the pathway. To this end one should consider all the n! situations which will increase dramatically with the number of pads involved and will be almost impossible to be calculated. The genetic algorithm is used here to obviate this obstacle.

## 3.4. The shortest pathway using the genetic algorithm

The genetic algorithm is a method based on a natural selection mechanism which is successfully used in many optimization problems. This algorithm holds several priorities [7]:

- Instead of dealing with the parameters, the algorithm deals with a set of coded parameters.
- In genetic algorithm a set of nodes are considered, not a single node.
- The genetic algorithm makes use of the data generated by the objective function itself, not using its derivatives or any other auxiliary data.
- The genetic algorithm avails from the probabilistic functions rather than any specific equation.

GA focuses on the available population to generate the children in the next generation. The algorithm choice parents with best characteristic and transfers them to the mating pool for the genetic algorithm. After the genetic operands are applied, based on Elitism criterion, a number of parents and children are selected for the next generation. This cycle of reproduction and natural selection continues until one of the genetic termination criteria is satisfied. The flow chart of the genetic algorithm is shown in fig 2.

Before proceeding with the GA approach, there are two preliminaries to be finished [8].

*Definition of suitable Coding*: To solve optimization problems with the genetic algorithm, coding is of great importance. Coding projects the parameters from a real domain to a solution domain, in which the problem is being dealt with using the genetic algorithm. Each chromosome is considered as a sample response in the solution domain and is composed a number of genes. The number of genes depends on the number of variables intended to be chosen. Fig.3 shows a sample coding to solve an optimization problem along the drill pathway. If n output nodes in the pad-list are considered, each gene of a chromosome can be taken as an index of a specific node. As a result, the chromosome will hold n bits of genes.

*Choice of fitness function:* For each chromosome of the population being studied, a number of fitness is attributed and as the genetic algorithm as a maximizing process, one can choose the fitness function to be the inverse of the objective function. To optimize the system using the genetic algorithm, regarding the objective function selected in equation 2, one can choose the fitness function as

$$F = \frac{1}{D} \tag{3}$$

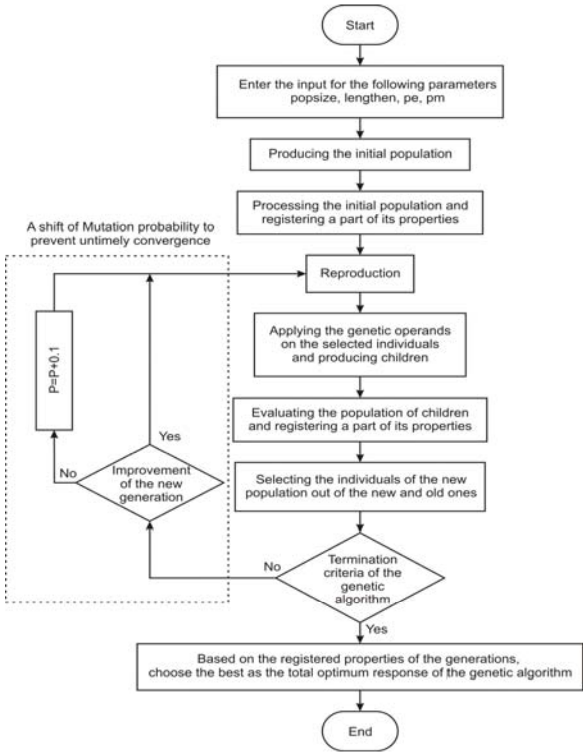


Fig. 2: the flow chart of the genetic algorithm.

Based on a flowchart on fig. 2 and the tow preliminaries carried out, the sequences of the genetic algorithm are:

*Generating the initial population:* Several patterns (chromosomes) are selected out of the same set randomly. The number of these patterns or chromosomes which is the number of population can be user defined.

Evaluating the objective function: At this stage, based on the selected fitness function, it is estimated that how fit (deserving) is every member of the population.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2 | … | I | … | J | … | N |

Fig. 3: A sample chromosome in the solution space.

*Reproduction:* This stage involves coupling the patterns randomly to be sent to the mating pool and reproduce the next generation with the genetic and reproductive operands.

*Crossover:* Fig4 shows the process through which children are produced using the crossover operand. First each pattern is divided into 3 parts while the edge elements receive (n/4) bits and the elements in between receive (2n/4) bits.

*Mutation operation:* At this stage the [2n/4] bits are

```
                  *        *
Parent1   (3  5  7  2  1  6  4  8)
Parent2   (2  5  7  6  8  1  3  4)

Child1    (5  8  7  2  1  6  3  4)
Child2    (3  5  7  6  8  1  2  4)
```

Fig. 5: the execution method of the mutation operand.

selected to be replaced by [n/8] at the left and right edges, as shown in fig. 5.

```
                  *        *
Before:   (5  8  7  2  1  6  3  4)
After:    (5  8  6  2  1  7  3  4)
```

Fig. 4: The execution method of the crossover operand.

*Elitism:* Among the population of the parents and the children, the chromosome of the next generation is selected based on the fitness function.

*Termination criterion:* At this stage it is decided whether the genetic algorithm stops or not. The criteria of termination at this algorithm may be active or passive. In the passive form, the number of stages of reproduction is decided by the user who chooses the number of generations. In the active criterion, if in a number of consecutive generations no change happens (the number of these generations is defined by the user), that is, the value of the fitness function does not improve, the algorithm terminates.

## 4. Simulation

To see how effective the proposed algorithm in minimizing the automatic drill's pathway is, the algorithm is applied on a group of test data which are the output data of the PCB design softwares such as Protel, OrCAD, EasyPC and the like.

In fig. 6 the pattern test is shown without a sorting function which shows the pathway followed by the automatic head-rail to be 25290 units.

Fig. 7 rearranges (sorts) the test pattern based on the x-then-y method. As can be seen in the figure the head-rail motion is zigzag and the total pathway is 17717 units.

Fig. 8 the motion of the drill is shown using the Snakelike method. It is seen that the distance of the nodes at every zigzag jump is reduced and the total pathway shrinks to 5574 units.

Fig. 9 The head-rail motion (pathway) is shown based on the nearest node to the existing node method. It is observed that this algorithm holds some errors which originate from an accumulative distance from the blind nodes and consequently the drill needs more time to reach these nodes compares to the rest of the nodes. The total pathway on the test pattern based on this method is 4785 units.

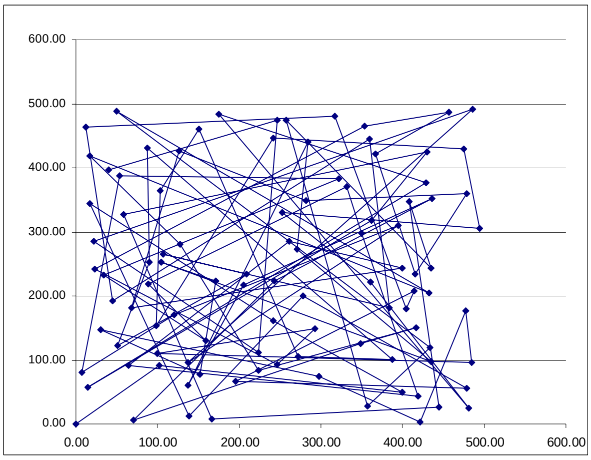


Fig. 6: Exploring the pads based on the initial list.

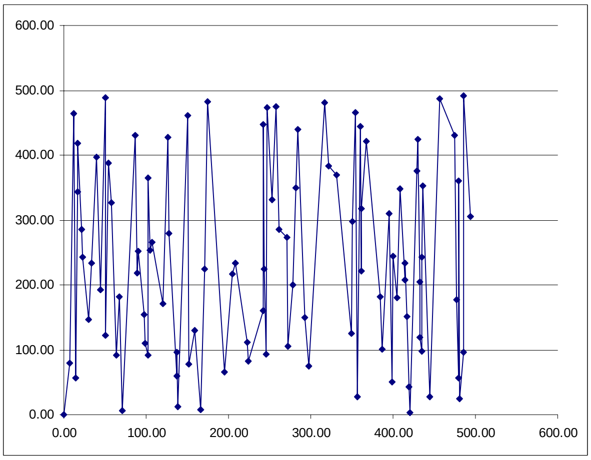


Fig. 7: exploration of the pads based on the list sorted by the x-then-y algorithm.

Fig. 10 shows the convergence of the GA. That after 16 it oration the algorithm reach the optimal value. In practicing the genetic algorithm the genetic parameter involved are provided in table 1. The results of pathway are shown in fig. 11. According this figure total pathway using this method is 4172 units.

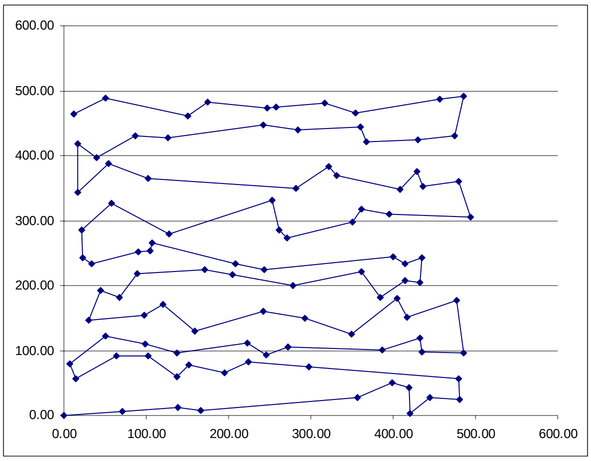


Fig. 8: Exploration of the pads based on the list sorted by the Snakelike algorithm.

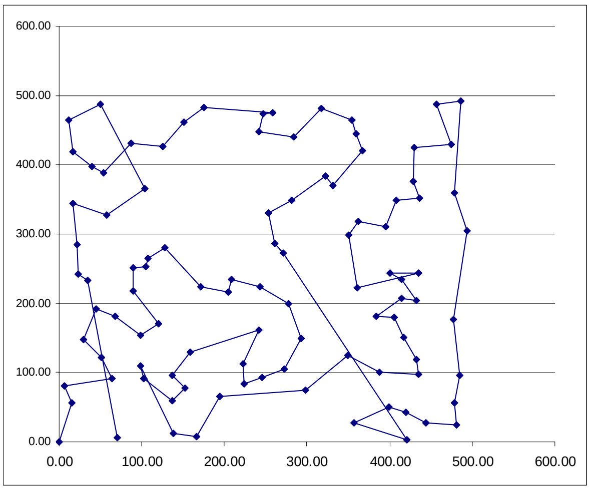


Fig. 9: Exploration of the pads based on the minimum distance algorithm.

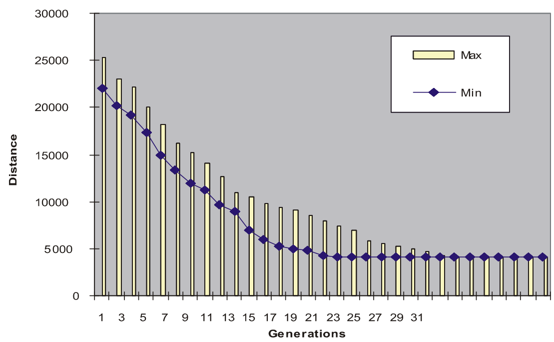


Fig. 10: The convergence diagram of the genetic algorithm

| Max Gen | $P_c$ | $P_m$ | Pop size | Active condition |
|---|---|---|---|---|
| 100 | 0.9 | 0.1 | 20 | 15 generation with out improvement |

Table 1: Genetic algorithm parameter.

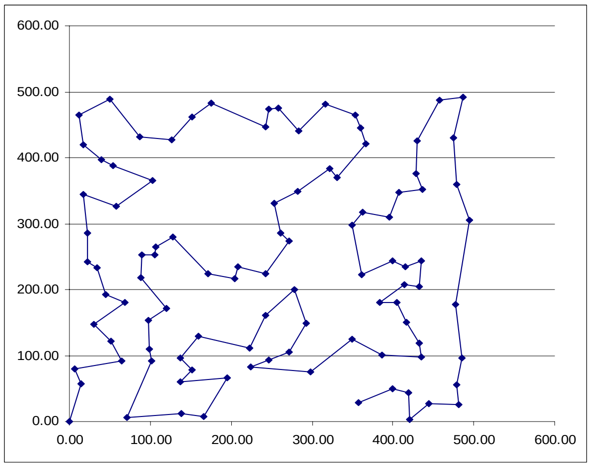


Fig. 11: Exploration of pads based on the genetic algorithm.

To demonstrate the performance robustness of the proposed method, the Absolute Error (AE), Mean Square Error (MSE), Mean Percentage of Absolute Error (MPAE) based on pathway characteristic are being used as:

$$ABSE = \sum_i \left| D_{iG} - D_{iK} \right| \tag{4}$$

$$MSE = \frac{\sum_i (D_{iG} - D_{iK})^2}{n} \tag{5}$$

$$MPAE = \frac{\sum_i \frac{\left| D_{iG} - D_{iK} \right|}{D_{iG}} \times 100}{n} \tag{6}$$

where:

*i: node number index*

*n: total number of nodes present*

*G: indicates the genetic algorithm*

*K: indicates the other arrangement methods. K belongs to all the arrangement methods.*

*Dig: The distance of the 'i$^{th}$' point using the genetic algorithm*

*Dik: The distance of the 'i$^{th}$' point using other arrangement methods*

The values of AE, MSE and MPAE are calculated for each method and listed in table 2. This table shows that:

| | ABSE | MSE | MPAE |
|---|---|---|---|
| No Sort | 21147 | 59922 | 677 |
| x then y | 14063 | 33138 | 420 |
| Snake | 2970 | 1924 | 98 |
| min dist. | 2906 | 2159 | 83 |

Table2: The errors of different algorithms being compared to the genetic algorithm.

1. The x-then-y method holds less distance error compared to the unsorted list.
2. The snakelike method holds also holds less error compared to the x-then-y method.
3. The min distance method holds less error compared to the previously mentioned methods.
4. using the genetic algorithm may guarantee that a complete optimized pathway could be found. As a result the drill will move on a minimized pathway and this is economic both regarding the device depreciation and time.

To evaluate the improvement, the criterion MR% in equation 7 is used and the result is provided in table 3. This table shows that using the genetic algorithm improves the optimized result by 83.5%.

$$MR\% = \frac{\sum_i D_{i(nosort)} - \sum_j D_{j(metods)}}{\sum_i D_{i(nosort)}} \times 100 \qquad (7)$$

| | MR% |
|---|---|
| x then y | 29.9 |
| Snake | 77.2 |
| Min Dist. | 81.1 |
| Genetic | 83.5 |

Table. 3: Comparing the extent of improvement.

The above results show that in comparison with other methods, the system performance is significantly improved by GATP.

## 5. Conclusions

In this paper a new GA based traveling pathway is proposed to minimize the movement of automatic drilling of printed circuit boards. This strategy was chosen because of increasing complexity of optimizing problem for bigger boards. It should be noted that to achieve the desired level of robust performance, minimizing the total pathway is very important. Thus to reduce the classical method efforts and increase cost saving, a GA ha s been used to choose the best pathway. In this work GA works offline and is used to find the optimal total pathway. This proposed method can guarantee the optimum value of the fitness function.

The salient feature of the proposed method is that the design process is less demanding that other methods. The proposed GATP was tested on a 100-node pattern to demonstrate its effectiveness. Simulation results show that the proposed is very effective and achieve good robust performance. The system performance characteristics in term of AE, MSE, MPAE and MR% indices reveal that the GATP is promising method for solution of the traveling pathway between PADs in the automatic drilling of printed circuit boards and superior to traditional methods. This is lead to the reduction in the distances, minimization and optimization of the reaction period, the error and depreciation of the system. Thus it is recommended to optimization total pathway traveling problem.

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