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Tool path optimization for drilling holes using genetic algorithm

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Abstract
In CNC machining operations it is essential to improve the efficiency of the machine in terms of time, energy consumption etc. Drilling a large number of holes is widely practiced machining operation in manufacturing industries like in PCB manufacturing industry. For increasing the production rate, it is essential to optimize tool path such as reducing air time of tool path, drilling all the holes in the shortest path etc. A model for CNC drilling is designed in solid works, the co-ordinates of the holes is exported to excel, and thus optimization technique is used to find the optimal path. The optimal path is compared to that obtained from a commercial CNC software NC plot v2.34. This project is an attempt to optimize tool path in terms of shortest route for drilling a large number of holes in part. However, this technique may be applied to other CNC machining operations. The optimization of path is accomplished using evolutionary algorithm in solver.

Keywords: Genetic algorithm, evolutionary, solver, excel, tool path, optimization

1. Introduction
The demand of manufactured part is growing. It is essential to increase the efficiency of production in terms of time, energy and cost. It must increase the production for increasing demand by increasing the production rate. In manufacturing industry, machining is widely done. Use of CNC machinery has been increased widely in all industries. Various method are developed to automate the working of the machine and optimize the tool path. The optimization of tool path is must to increase the production rate by minimizing the length of path travelled by the tool, reducing air time. There may be other factors like least energy consumption path, path considering minimum force to machine, tool life, thermal factors etc. Tool path optimization may be viewed as Travelling Salesman Problem (TSP) where number of places is to be visited travelling the least distance. Network modeling can be done to this problem and be solved by linear programming. For optimization of the tool path, Genetic Algorithm (GA) can be used for a given constraints. Use of GA has been described as 'robust' optimization technique to solve optimization problem as compared to other techniques because it covers large varieties of problems. Researchers have been concerned with the cost of machining (Boothroyd, 1975) [1]. Optimization of cutting parameters like feed rate and depth of cut is usually a difficult work where the following aspects are required: knowledge of machining, empirical equations relating to tool life, surface finish and so on. (Sardinas, Santana, & Brindis, 2006) [7]. Criterions like machining time, material removal rate and tool life have been used in optimization procedure. (Chua, Wong, & Rahman, 1991) [2].

1.1 Nomenclature
CAM Computer Aided Machining
CNC Computer Numeric Control
GA Genetic Algorithm
TSP Travelling Salesman Problem
PCB Printed Circuit Board

1.1.1 Travelling salesman problem
A Travelling Salesman Problem (TSP) is that where a salesman need to travel the all the places to deliver goods and return to origin in shortest path. Although TSP is conceptually simple, it is difficult to obtain an optimal solution. The main difficulty of this problem is the

enormous number of possible tours; (n1)!/2 for symmetric n cities tour. As the number of cities in the problem increases, the numbers of permutations of valid tours are also increase. It is this factorial growth that makes the task of solving the TSP immense even for modest n sized problems (Razali & Geraghty, 2011) [6]. Tool path optimization may be viewed as TSP if the optimization is done for minimizing airtime. The tool may or may not need to reach where it started.

1.2 Genetic Algorithm

A genetic algorithm is a search heuristic that is inspired by Charles Darwin's theory of natural evolution proposed by Professor Holland from the university of Michigan. This algorithm reflects the process of natural selection where the fittest individuals are selected for reproduction in order to produce offspring of the next generation.

Standard genetic algorithms are divided into five phases which are:

- Creating initial population
- Calculation fitness
- Selecting best genes
- Crossing Over
- Mutating to introduce variations

The genetic algorithm depends on selection criteria, crossover, and mutation operators. To tackle the traveling salesman problem using genetic algorithms, there are various representations such as binary, path, adjacency, ordinal, and matrix representations (Hussain, Muhammad, & Hussain, 2017) [3].

2. Previous works

Various works done in tool path optimization was studied in published papers, journals. Some of them are:

A paper on Efficiency of Tool Path Optimization Using Genetic Algorithm in Relation to the Optimization Achieved with the CAM Software by Danijela Pezer, optimization of tool path is done using genetic algorithm by reducing to Traveling Salesman Problem and comparing it to solution than that produced by commercial software. The shortest route to drilling holes was found out to increase the efficiency than that of available software (Pezer, 2016) [5].

B. Raja Chinna Karuppanan in his paper titled "Optimized sequencing of CNC milling toolpath segments using metaheuristic algorithms" has presented an effective method that uses heuristic optimization techniques to solve this NP-hard problem, which is known as the traveling salesman problem, for segments. The purposed method implemented GA and PSO in the MATLABR 2016 b software and validated by comparing its results with those of two industry standard CAM systems, namely, Autodesk Inventor HSM and Mastercam and suggested method was found to save up to 40% of the tool's airtime during machining.

3. Methodology

3.1 Development of Mathematical Model

The mathematical model of the problem was developed in terms of objective function and constraints. The input of the variables was to be holes co-ordinates.

$$\textbf{Objective function: Minimize } \sum_1^n d(h_i, h_{i+1})$$

$$\text{where } \mathbf{d}=\sqrt{(x_{i+1}-x_i)^2+(y_{i+1}-y_i)^2}$$

h_i is hole index

x_i, x_{i+1} and y_i, y_{i+1} are co-ordinates of successive holes respectively

Subjected to constraints

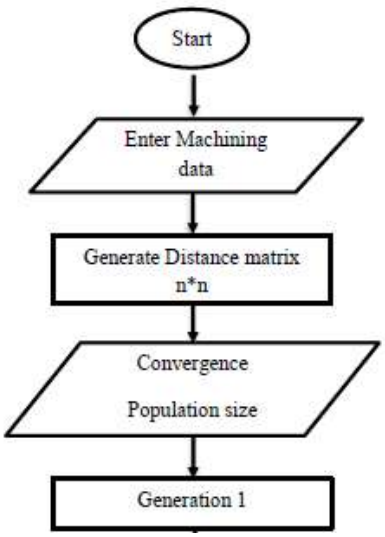
1. $h_i =$ all integer
2. h_i = all different
3. $1 \leq h_i \leq n$, n is the number of holes

3.2 Implementation

Development of model: Model of manufacturable model with number of holes was developed in SolidWorks, the number of holes in the design kept 61 in case of PCB, the co-ordinates of the hole was exported to excel.

Excel: Distance between a point and every other point is calculated using distance in Euclidean plane. A distance matrix of order n x n was obtained. Variables were set and objective function was set by using the sum of distance between all consecutive points on the path set by unique variable combination to represent all holes.

Genetic Algorithm Parameters: The objective function value was minimized using solver using evolutionary algorithm. It is better to use dynamic genetic algorithm parameters like mutation ratio and cross-over ratio but the solver supports static ratio only. However, the parameter values are taken using references from published works.



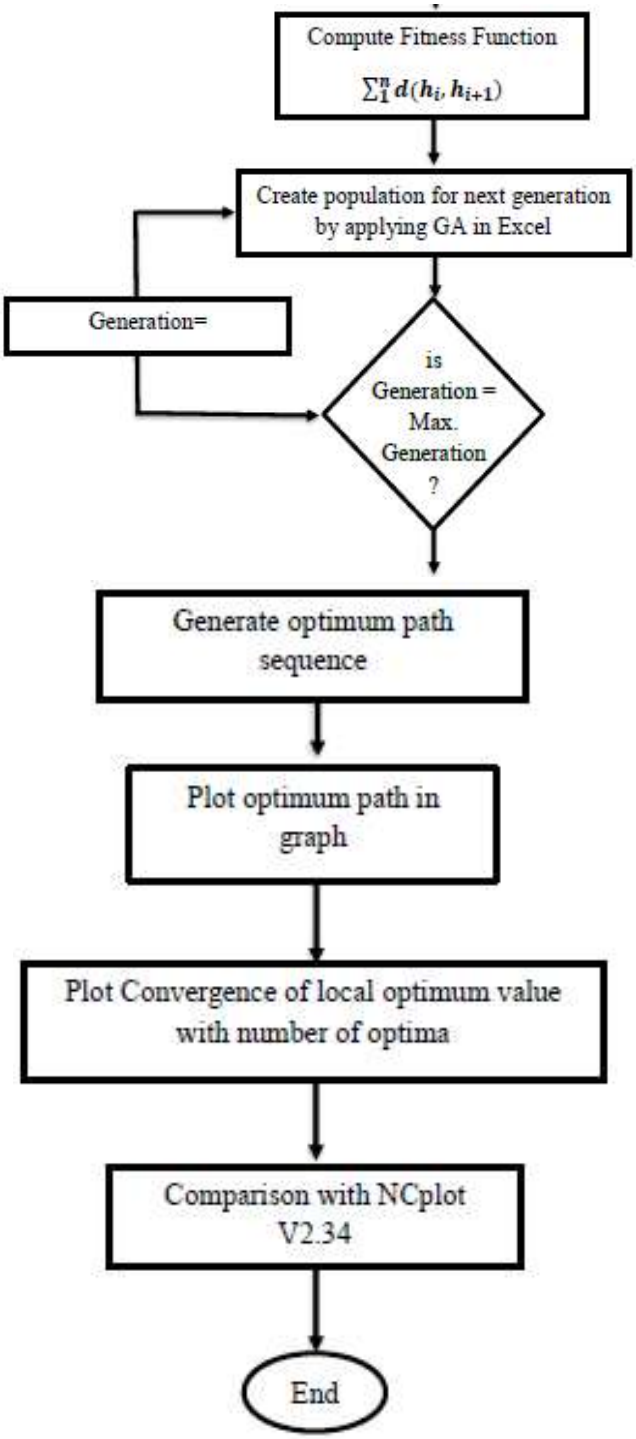


Fig 1: Methodology Chart

4. Discussion

The solution of the model was obtained as sequence of holes. The co-ordinate of holes was potted in graph to show the optimized path. The optimized result was compared to that of path obtained by commercial software NC plot for same model. The coordinates of the holes to be drilled for PCB model and model with circular holes pattern after being exported from Solid works were used in Excel to be optimized by using Genetic Algorithm. The various steps done are described below:

4.1 CNC drilling hole paths

4.1.1 GA parameters

In excel solver, the dynamic mutation and crossover parameters cannot be set so we set the static values for the parameters.

Table 1: Static values for the parameters

Parameter	Value
Population Size	10
Mutation rate	0.7
Convergence	0.000001
Random Seed	100

4.1.2 Raw hole data and optimized path

The raw hole data was obtained from the solid works model and was exported to excel. The initial plot of tool path was done and after the optimization problem was solved, the optimized tool path was obtained which is shown in figure 2

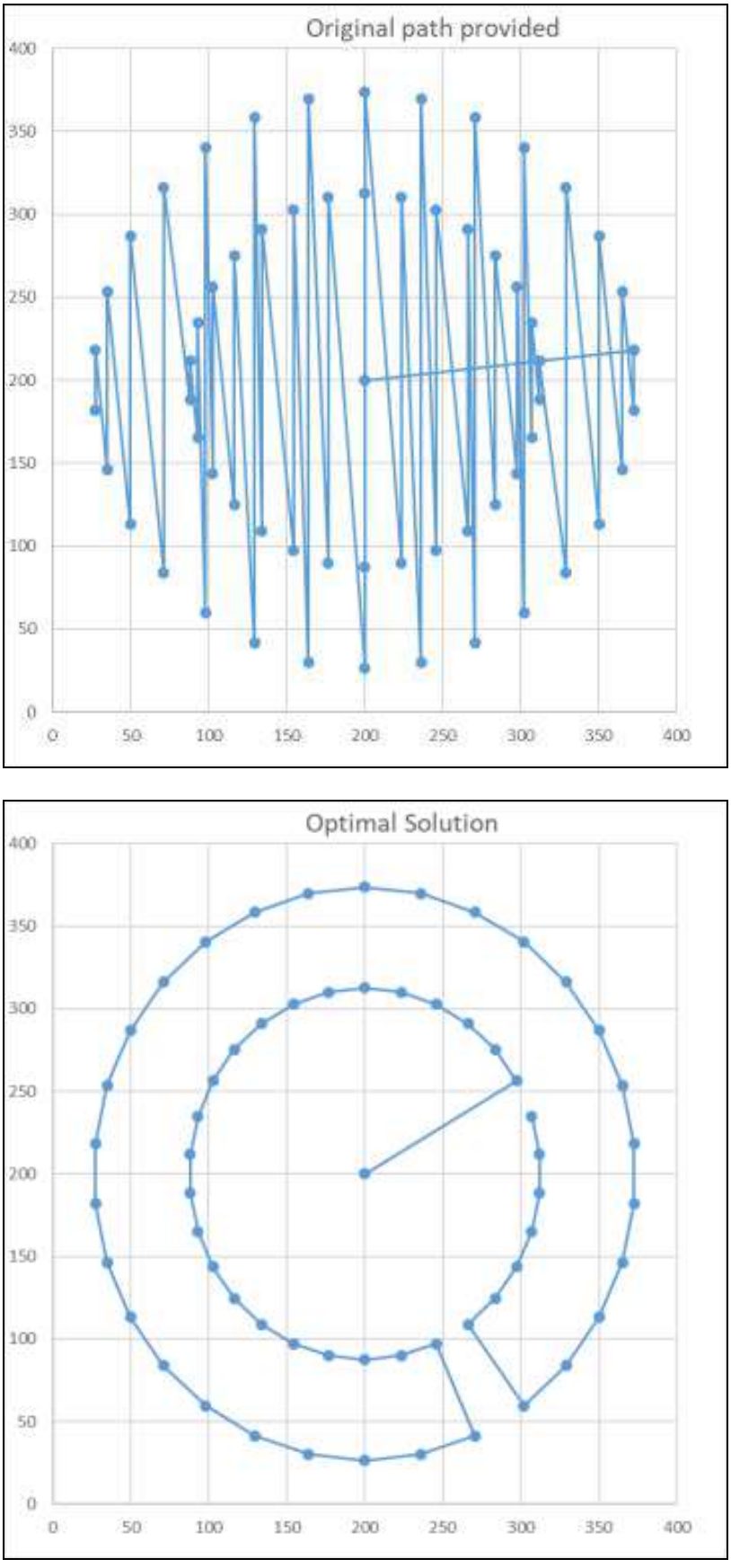
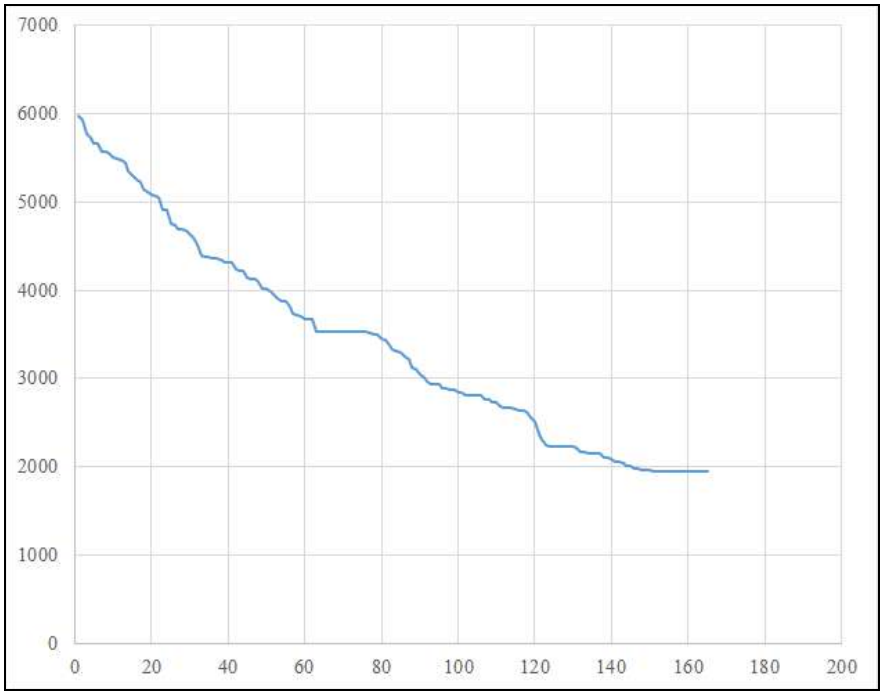


Fig 2: Tool path of raw data Vs Optimized tool path using GA

4.1.3 Convergence graph

As the objective function value was being calculated by the solver using evolutionary algorithm, the optimum value obtained by then was stored and plotted with increase in number of obtained local optimum solutions can be shown in a graph. The obtained graph below shows how optimal solution is achieved.



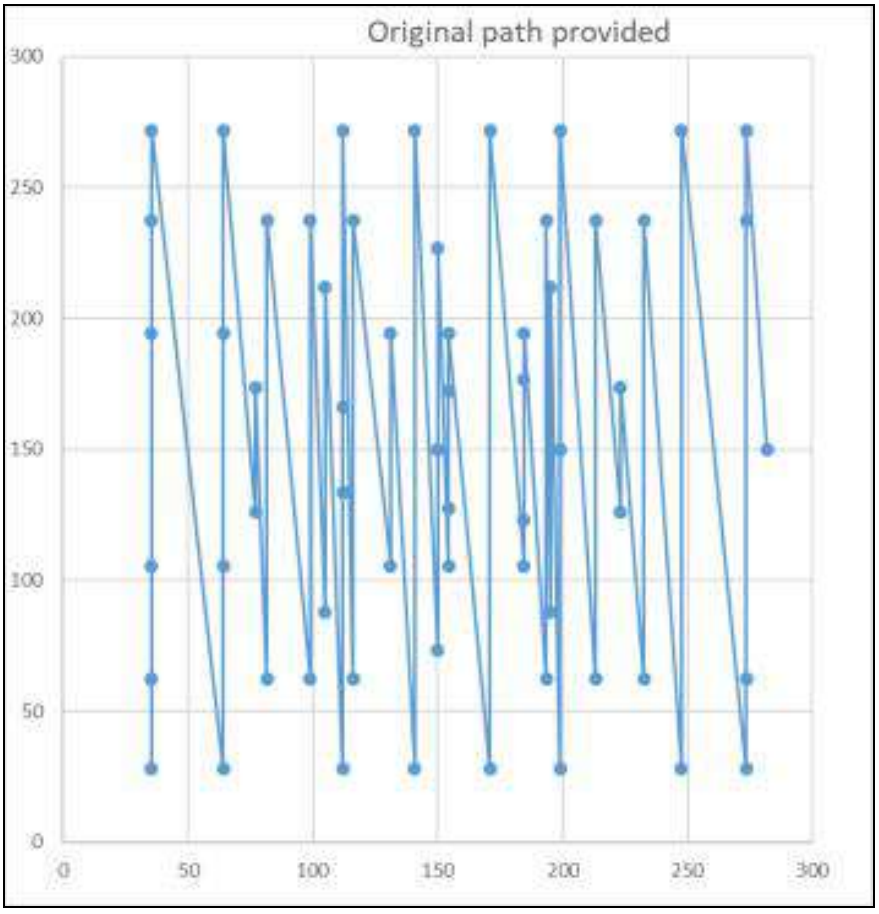


Fig 3: Convergence Graph

4.1.4 Comparison with NCplot v2.34 software

The tool path of circular pattern hole model obtained from a commercial software NCplot v2.34 is shown below. The total length of tool path for this model was obtained as 1945 mm from GA in excel where as for the same model the total length of tool path from NCplot v2.34 was obtained as 13959 mm.

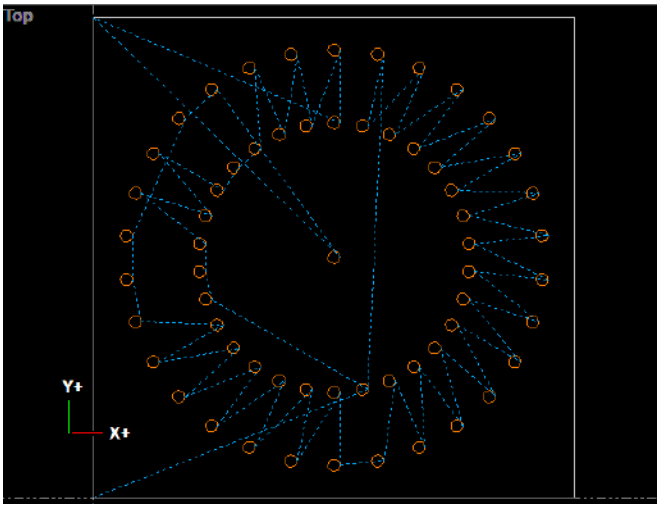


Fig 4: Tool path for circular holes pattern by NCplot v2.34

4.2 PCB Drill Hole Paths

In excel solver, the dynamic mutation and crossover parameters cannot be set so we set the static values for the parameters as done in PCB model.

Table 2: GA Parameters for PCB drill holes

Parameter	Value
Population Size	10
Mutation rate	0.7
Convergence	0.000001
Random Seed	10

4.2.1 Raw hole data and Optimized path

The raw hole data was obtained from the Solidworks model and was exported to excel. The initial plot of tool path was done and after the optimization, the optimized tool path plotted is shown in the figure 5.

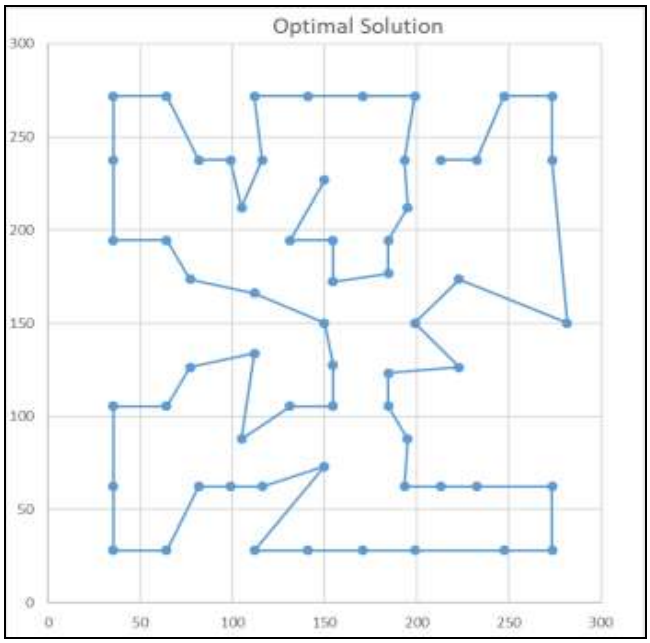


Fig 5: Path of raw data Vs Optimized tool path using GA for PCB holes

4.2.2 Convergence graph

The obtained graph below shows how optimal solution is achieved for obtaining path for PCB model.

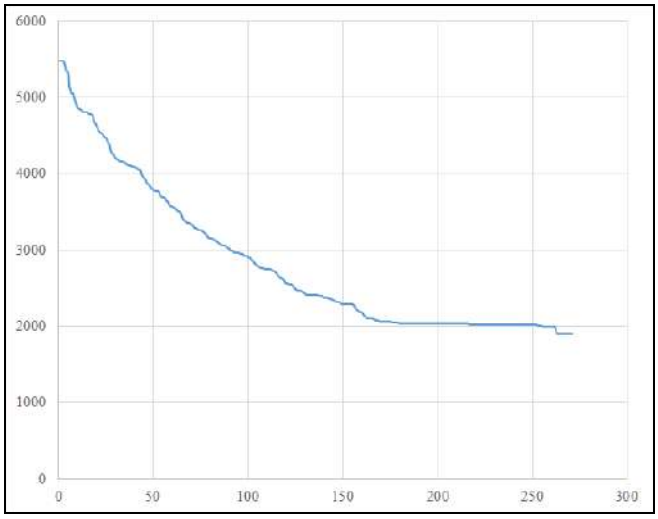


Fig 6: The Convergence graph for PCB

4.2.3 Comparison with NCplot v2.34 software

The comparison between the optimized tool path from our model and path obtained from a commercial software NCplot v2.34 was done. The total length of tool path for PCB model was obtained as 1902 mm where as for the same model the total length of tool path from NCplot v2.34 was obtained as 4361 mm.

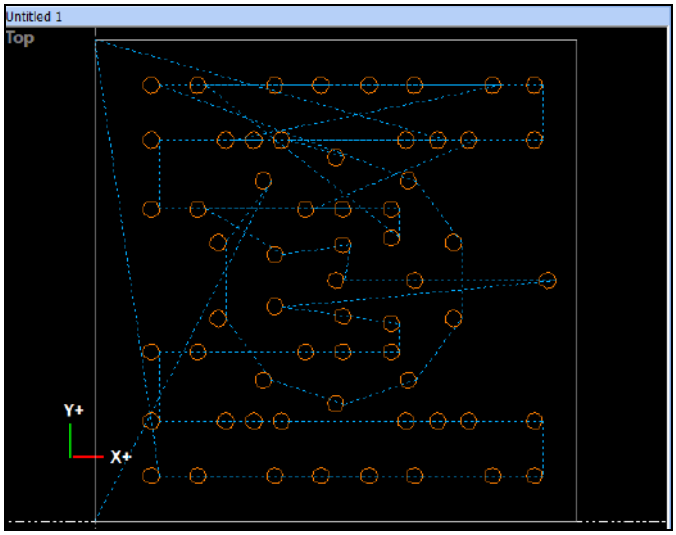


Fig 7: The total length of tool path for PCB model

5. Conclusion

In this optimization problem we obtained the tool path minimizing the total distance the tool has to travel to drill the holes at provided co-ordinates using genetic algorithm in solver in EXCEL. We performed the optimization of holes path for PCB and for model with circular holes pattern. The results were compared with that obtained by path from commercial software NC Plot \V 2.34. Table 3 summarizes the total length of tool path for two models.

Table 3: Total length of paths

Model	Length of Path from GA (mm)	Length of Path from NCplot v2.34 (mm)
Printed Circuit Board	1902	4361
Circular Holes Pattern	1945	13959

The length of too path for drilling holes in PCB was reduced by 56.38% and for model with circular holes pattern the length of the path was reduced by 86.06%. This optimization problem was solved in excel solver using evolutionary algorithm. GA has been described as robust optimization technique but the computation is slower. The solution time for hole path in PCB was 272.672 seconds and for model with holes path in circular pattern was 1644 seconds when the solution was run in Intel I5 7th Gen. This is very high time as compared to time taken by commercial software. The cost of machining has been greatly reduced by optimizing the tool path in terms of distance travelled but the cost of computation is still higher. However, for large scale manufacturing of similar products, the holes co-ordinates are same and thus the tool path, so computation need not to be done for all products. As a result cost is minimized.

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