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Tool Path Optimization of Drilling Sequence in CNC Machine Using Genetic Algorithm

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Abstract

Drilling is a one of the most common machining process. There are a lot of applications where drilling is used, like drilling of holes in the printed circuit boards. . CNC machines are used today to perform the drilling process. These machines are capital intensive, and their maximum utilization is due to their economic viability. An issue that affects the utilization of these machines is the drilling sequence, because usually there is a number of points that has to be visited. Determination of drilling sequence is similar to the Traveling Salesman Problem (TSP) and exhibits characteristics of an NP-hard problem. In this paper, a program to find the optimum shortest path was built, using Genetic Algorithm and Traveling Salesman Problem to shorten machining time for the drilling of a given group of holes and hence to reduce machining cost and improve CNC machining efficiency without degrading motion accuracy. The results showed the effectiveness of the genetic algorithm, and the machining time is reduced to around 50% in some cases and hence machining power and cost are reduced

Keywords: GA, Tool Path Optimization, CNC, Drilling

1. Introduction

By the automation of manufacturing, production of goods becomes a bunch of steps and sequences, like bolt sequencing, drilling and welding process steps. Most of these sequencing type engineering problems can be modeled as traveling salesman problems (TSP). In this paper, a Genetic Algorithm (GA) is used for the (TSP) to reduce the total time and distance of tool travel for drilling sequence in CNC machine. By using Traveling salesman problem, it becomes a little bit simple and less time consuming. But there are many possible sequences in TSP. So, there is a need to find out the best possible solution so that the process becomes more efficient and less time consumer.

2. Literature Survey

Many methods are used by related journal to optimize tool path in CNC machining system :

Medina-Rodríguez et al. (2012) **[1]**, presented an efficient solution to determine the best sequence of G commands of a set of holes for a printed circuit board in order to find the hole-cutting sequence that shortens the cutting tool travel path. A Parallel proposal of Ant Colony Optimization was used to find an optimal travel path, then the new G-codes sequence was used instead the original sequence as part of the process program. This application can be formulated as a special case of the Traveling Salesman Problem (TSP).

PINAR and G¨ULL˙U **(2005) [2]** , prepared an algorithm for minimizing the machining time of CNC part programs used in a vertical machining center. The CNC program is transferred from the machine to the CNC code editor with a serial cable (RS-232). The time calculator examines all the codes in the code editor and calculates the time of all the movements in minutes. The other processor, which does the code formation, analyzes each individual movement of machining. As a result, it orders all the operations formed with the same cutting tool on the x and y axes. It also generates the G codes by minimizing the rapid movements of the tool in terms of the shortest tool path. With the cutting parameters module, machine table feed and spindle speed are modified using the machine power and tool life as limiting factors for each machining operation. In this way, the CNC program is modified. By reanalyzing the new CNC program with the time calculation processor, the time saved can be seen.

Majid Tolouei-Rad (2011) [3], proposed a system for optimum tool path planning to improve the performance of the pocket milling operations via a combined mathematical-graphical approach. The improvement is achieved by maintaining material removal rate and resultant cutting forces and chatter within limits, and eliminating shocks on the cutting tool. This increases tool life and reduces the risk of tool breakage. Results have been verified by practical experiments, during which smoother surface finishes and noticeable reduction in machining vibration and noise have been observed. This is in addition to approximately 15% increase of the tool life and achieving more stable and safer machining operations. However, machining time has slightly increased due to reduction of average material removal rate and longer tool paths. It is intended to extend the research in order to cover a wider range of milling operations, particularly when machining sculptured surfaces requiring a 5-axis CNC machine. Initial experiments showed that the same principle can be applied to these operations.

3. Objectives of The Work

Building a program using Genetic Algorithm and Travelling Salesman Problem to shorten the machining time for the drilling of a given group of holes and hence to improve the CNC machining efficiency without degrading the motion accuracy, then applying the algorithm to real CNC machining task to demonstrate the effectiveness of the proposed method.

4. Traveling Salesman Problem

TSP is one of the most widely studied combinatorial optimization problems. The most common practical interpretation of the TSP is that of a salesman seeking the shortest tour through *N* cities, visiting each city exactly once and returning back to the starting city. The problem statement is deceptively simple, but it still remains as one of the most challenging problems in operational research. To solve such problems of any size is by enumerating each possible tour and searching for the tour with the shortest path. Each possible tour is a permutation of *1, 2, 3, . . ., N*, where *N* is the number of cities, so the number of tours is *n!*. When *n* is large, it becomes impossible to find the path of every tour in polynomial time. The TSP can be described mathematically as follows. Consider a complete digraph $G = (V,P)$ where V is the vertex set that represents the cities, $V = \{1, \cdots, N\}$, A is the arc set, $A = \{(i, j), i, j \in V\}$ and Dij is the distance between cities i and j. The TSP then can be solved by minimizing the total trip given by Eq. (1) below [4] .

$$\text{Minimize} \quad \sum_{(i,j)\in A} D_{ij}\lambda_{ij} \quad \text{subjected to:} \qquad (1)$$

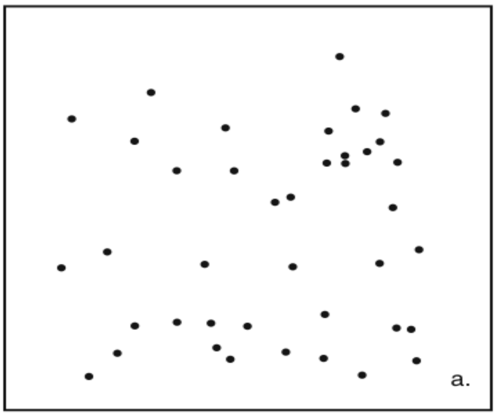
$$\lambda_{ij} \in \{0,1\}$$

$$\sum_{i\in V} \lambda_{ij} = 1 \qquad j \in V$$

$$\sum_{j\in V} \lambda_{ij} = 1 \qquad i \in V \qquad (2a)$$

$$(2b)$$

Constraints (2a) and (2b) ensure that each city is visited exactly once. The TSP is an NP-complete problem heuristic algorithms that have relatively short running times and often give solutions that differ only slightly from the optimal solution. Several methods, usually based on search heuristics, have been applied for the traveling salesman problem, such as Greedy Algorithms, the Nearest Neighbor algorithm, A minimum spanning tree, simulated annealing, neural networks. One of the methods for solving the TSP is genetic algorithms (GA). GA is global optimization techniques using various optimization problems, such as the TSP. The conditions being, the travelling salesman has to visit each city once and needs to get back to the start city at the end of the tour. The hard part is due to the fact that if one considers n cities, then one has to probably determine them systematically and finally find the minimum path length. This requires at least (n-1)! steps, n>3. So, if one considers a problem with 10 cities then is equal to figuring out the minimum of 9! = 362880 different paths. This will increase rather exponentially as n increases and it will take ages to verify each route and figure out the minimum length. And for 40 cities, then is equal to $39! = 20\ 397\ 882\ 081\ 197\ 442 \times 10^{30}$, as shown in Figure 1.



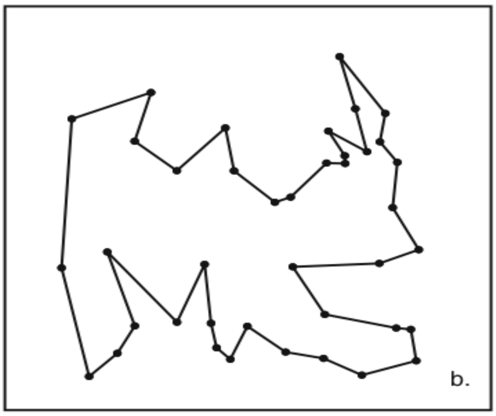


Figure 1a. 40 nodes TSP

Figure 1b. Shortest path using GA

5. Implementation

In this research work, MATLAB 7.14.0.739 (R2012a)" is used. MATLAB is the sort form of Matrix Laboratory. MATLAB takes the input data in the Matrix form so due to this quality, it got the name MATLAB. The procedures of programming of modal using MATLAB software are described in the following steps:

1. Determination of the position of the point
2. Specify GA parameters
3. Initialize the population to run the GA by evaluating each population member
4. Coding for finding the best rout in the population
5. Coding for GA operator
6. Coding for display the graph and result

The Flowchart shown in figure 2 describes the procedure of finding the shortest path of the desired points to be machined by applying GA into TSP.

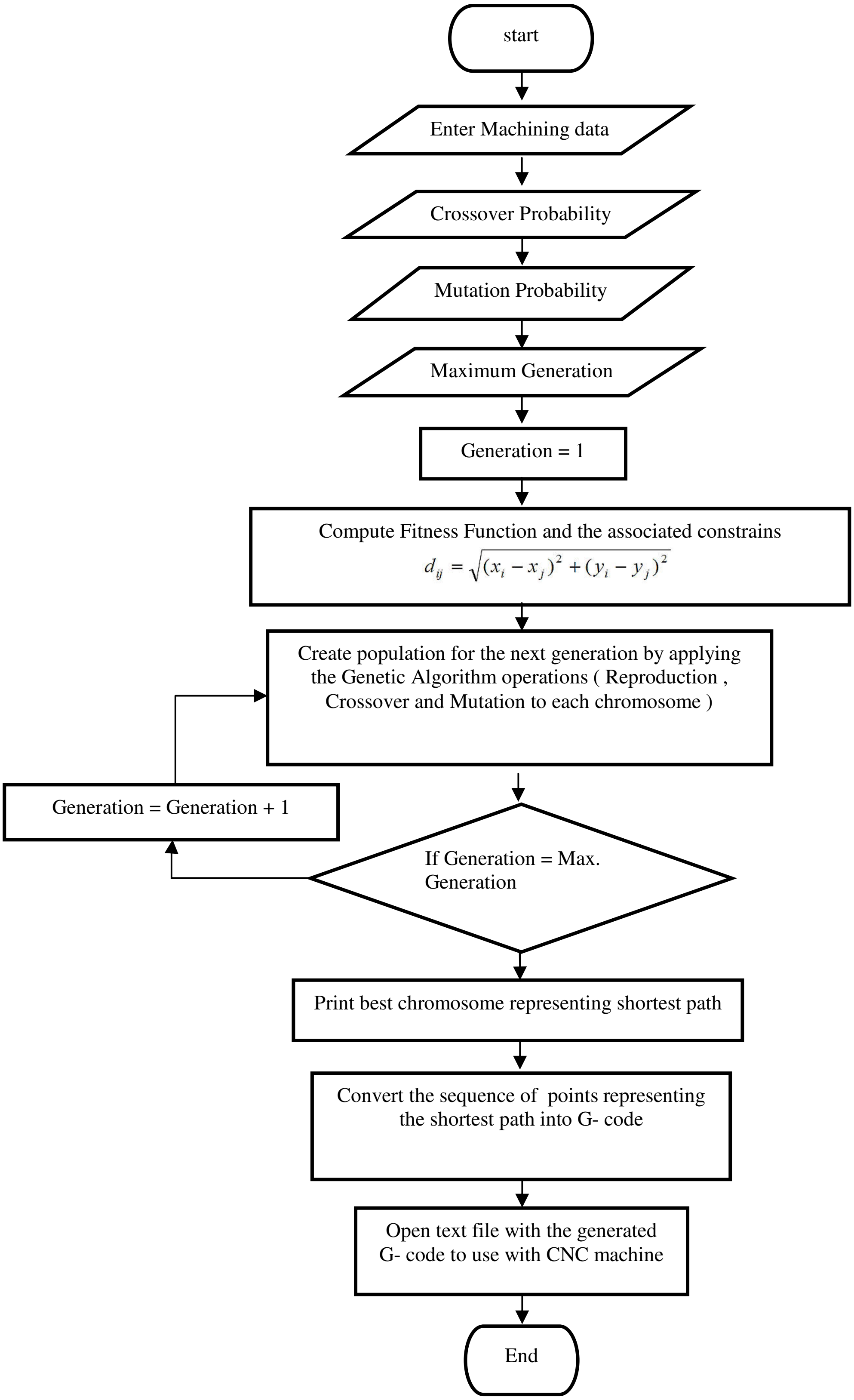


Figure 2. Flowchart of finding shortest path by applying GA on TSP.

6. Parameters Settings

It is found that the following parameters as shown in table 1 give better results for non-productive machining time problem to run GA and TSP. As the algorithm is being tested over different sized node problems, therefore varying population sizes are considered.

Table 1 Parameters for Genetic Algorithm

Parameter	Value
Population Size	100 and 200
Crossover Function	Partially Matched Crossover (PMX)
Mutation Function	Reciprocal Exchange (RX)
Elite Count	2
Crossover Fraction p_c	0.8
Mutation Fraction p_m	0.08

The Machining data and coordinates of points to be machined are entered to the program. The program will apply TSP using GA technique onto the entered points. After running , the program will display the sequence of points that representing the optimum shortest path as shown in figure 3 , also a text file will be opened containing the G-code of the sequence of shortest path, as shown in figure 4 .

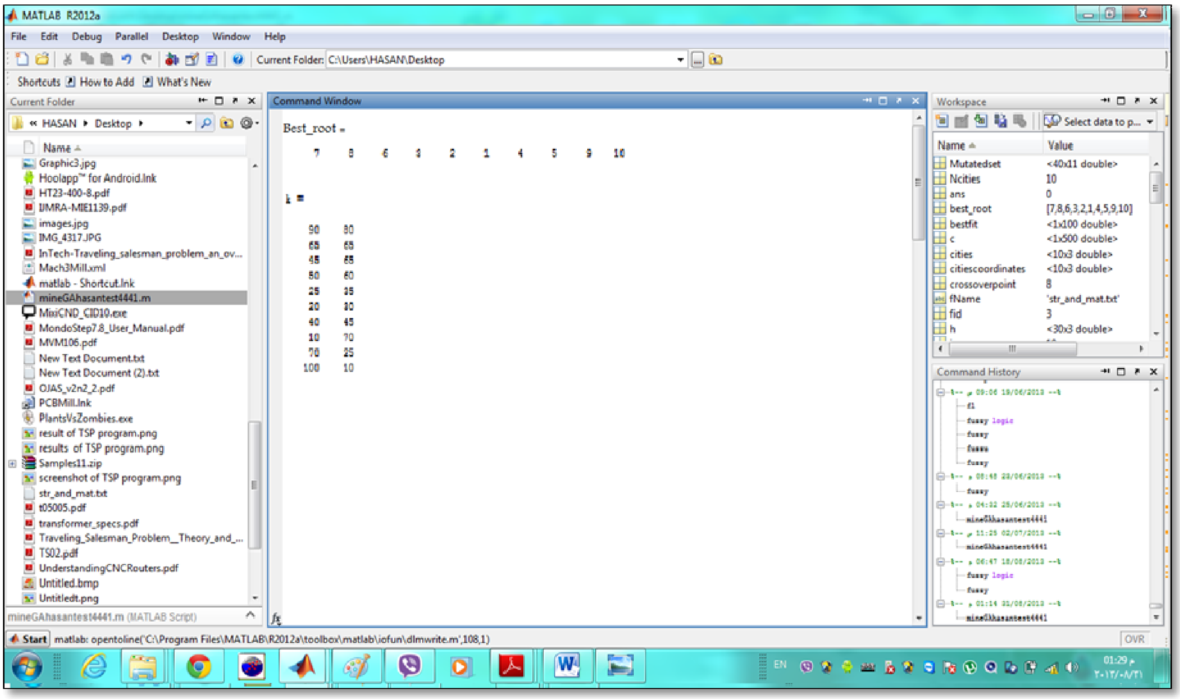


Figure 3. Screenshot of MATLAB program results

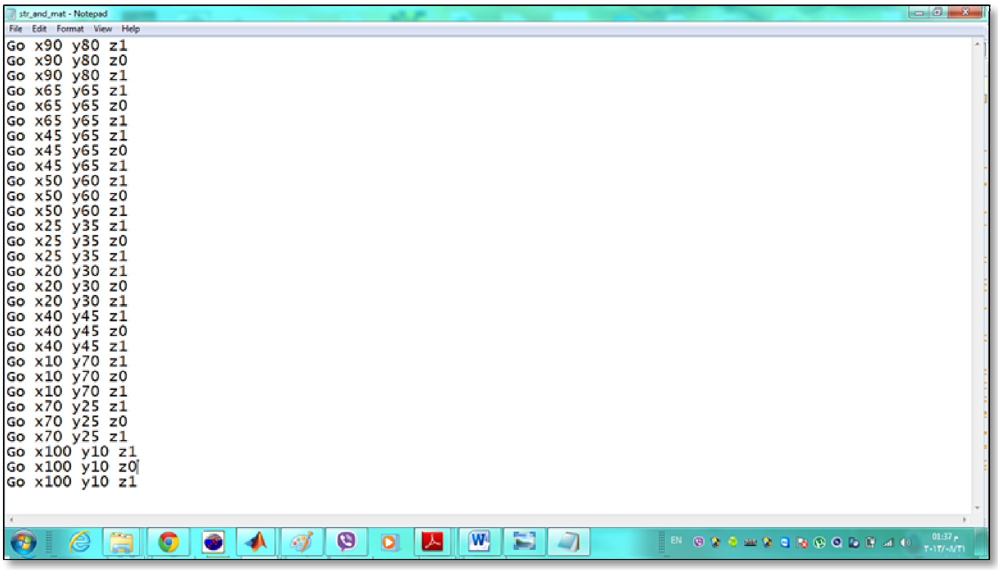


Figure 4. Screenshot of the opening text file which contains the G-code of optimum shortest path

7. Results Discussion of Genetic Algorithm for Optimum Shortest Path

In this section, the experimental results for the algorithm developed to find the shortest path will be explained. Results of optimum path generated using GA will be compared with the paths obtained with the famous CAM software "ArtCAM", where this software can produce many paths using various sequencing techniques. This comparison will be achieved via the following case studies.

7.1 Case Study1: Tool paths with 10 holes

First case study includes ten points or holes shown in figure 5 with the coordinates in table 2 .

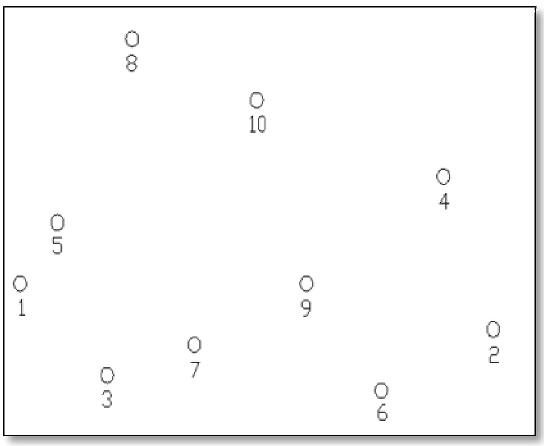


Figure 5. Ten holes of case study1

Table 2. Coordinates of the ten holes of case study1.

n	x	y
1	10	80
2	390	50
3	80	20
4	350	150
5	40	120
6	300	10
7	150	40
8	100	240
9	240	80
10	200	200

The path produced from the software depends on the technique used , the techniques used in the software are:

- Text order as shown in figure 6
- Left to right as shown in figure 7

- Bottom to top as shown in figure 8
- Spiral out as shown in figure 9

In addition to that, the optimum shortest path generated from applying GA and TSP to the ten nodes is shown in figure 10 . Also, machining time for each path is illustrated in table 3 .

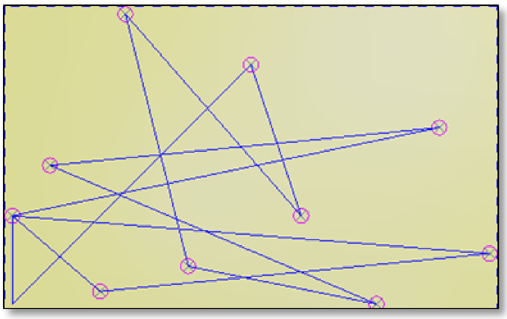


Figure 6. Text order technique with 10 holes problem

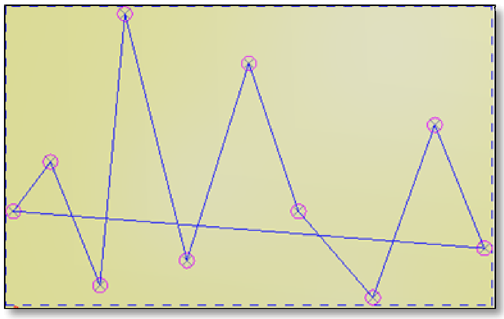


Figure 7. Left to right technique with 10 holes problem

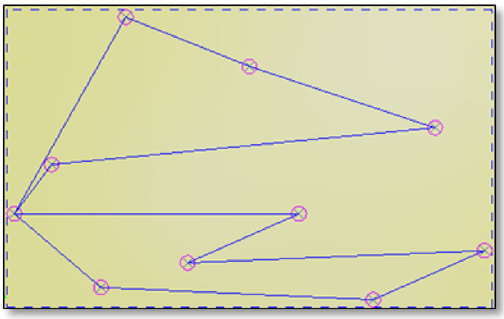


Figure 8 . Bottom to top technique with 10 holes

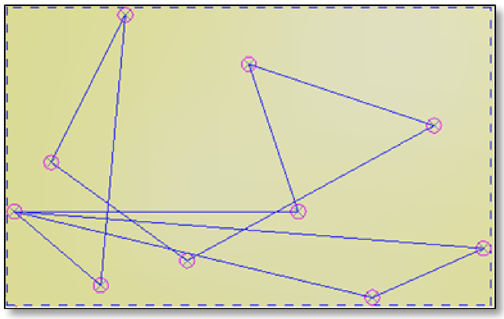


Figure 9. Spiral out technique with 10 holes problem

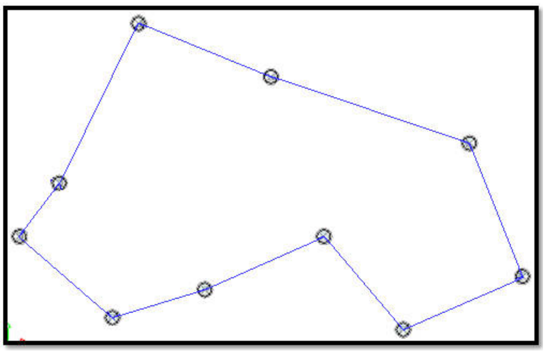


Figure 10. Optimum shortest path using GA technique with 10 holes problem

Table 3. Summary of results of machining time between ArtCAM techniques and GA technique for 10 holes problem.

n	Technique	Machining time Min : sec
1	Text order	02:31
2	Left to right	02:21
3	Bottom to top	01:54
4	Spiral out	02:12
5	Optimum path using GA	01:50

The difference in machining time between the techniques used above is explained in figure 10 .

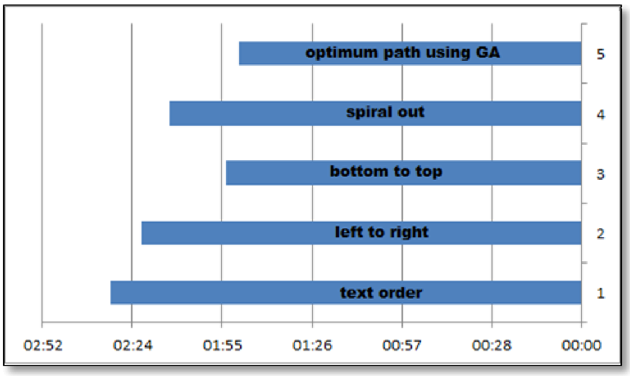


Figure 11. Comparison of machining time between ArtCAM techniques and GA technique for 10 holes in case study1.

7.2 Case Study2: Tool paths with 80 holes

This case study includes eighty points or holes shown in figure 12, the difference between the used techniques in terms of decreasing machining time is clear in this case of large number of points and special shape.

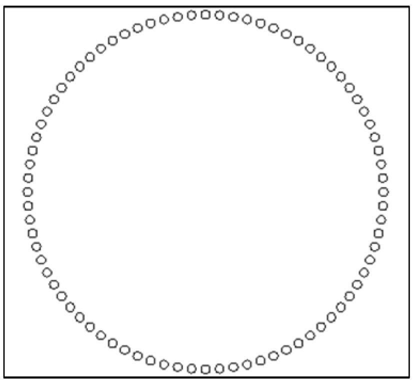


Figure 12. 80 holes of case study2

The techniques used in the software are:

- Text order as shown in figure 13
- Left to right as shown in figure 14

- Bottom to top as shown in figure 15
- Spiral out as shown in figure 16

In addition to that, the optimum shortest path generated from applying GA and TSP to the eighty nodes is shown in figure 17 . Also, machining time for each path is illustrated in table 4

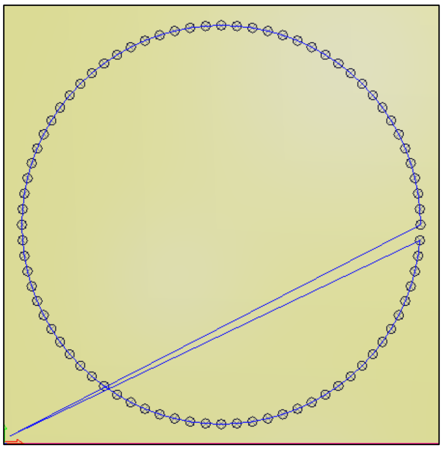


Figure 13. Text order technique with 80 holes

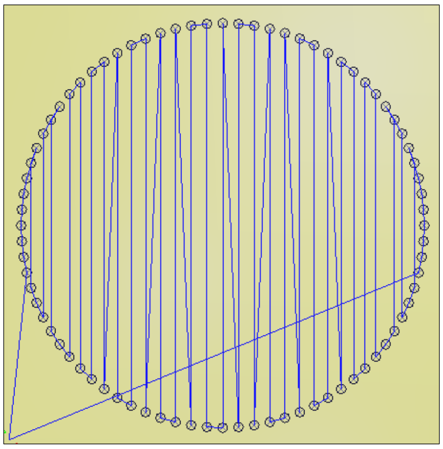


Figure 14. Left to right technique with 80 holes

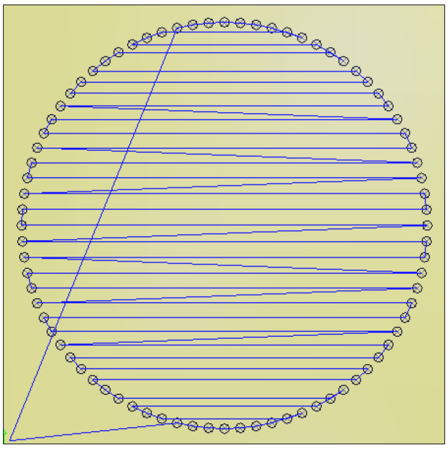


Figure 15. Bottom to top technique with 80 holes

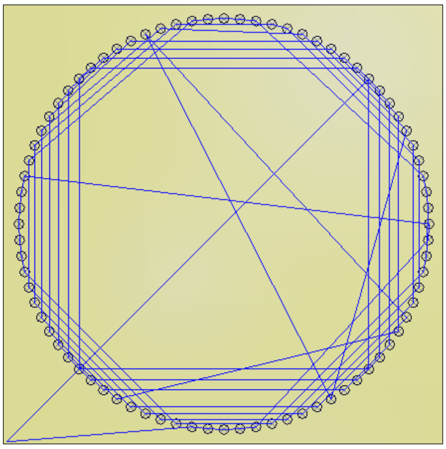


Figure 16. Spiral out technique with 80 holes

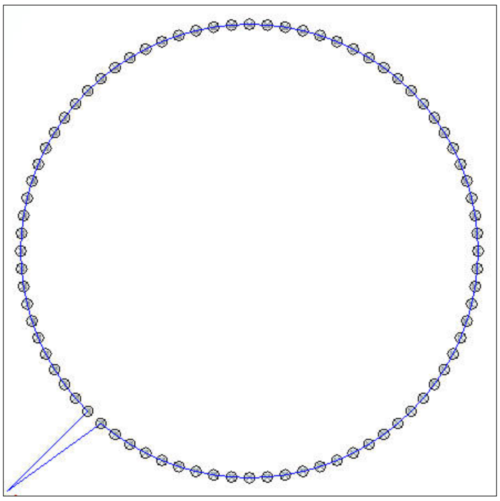


Figure 17. Optimum Path using GA technique with 80 holes problem

Table 4. Comparison of machining time between ArtCAM techniques and GA technique for 80 holes problem.

n	Technique	Machining time Min : sec
1	Text order	11:27
2	Left to right	21:46
3	Bottom to top	21:41
4	Spiral out	17:05
5	Optimum path using GA	11:08

The difference in machining time between the techniques used above is explained in figure 18 .

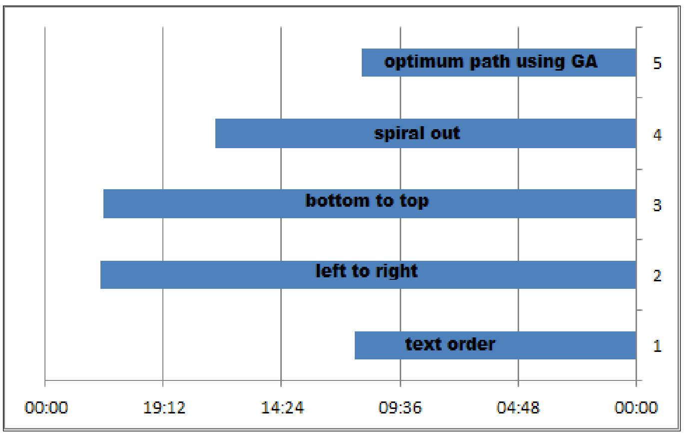


Figure 18. Comparison of machining time between ArtCAM techniques and GA technique for 80 holes in case study2.

8. General Discussion

It can be concluded that the Genetic Algorithm is an effective algorithm that can be used in the optimization of drilling path using TSP technique . However, Effectiveness of this algorithm is seen clearly with a large number of points and complicated paths in terms of computational time and the length of path, as seen in the results obtained previously.

Generally, GA has the best performance against Left to Right, Bottom to top and Spiral out techniques, as shown in tables 5 and 6 in terms of percentage machining time improvement.

Table 5. Machining time improvement of GA technique (with 110 Sec) against ArtCAM techniques for 10 holes

n	Technique	Machining time (Sec)	GA Improvement % Against this technique
1	Text order	151	27.15
2	Left to right	141	21.98
3	Bottom to top	114	3.50
4	Spiral out	132	16.66

Table 6. Machining time improvement of GA technique (with 668 Sec) against ArtCAM techniques for 80 holes

n	Technique	Machining time (Sec)	GA Improvement % Against this technique
1	Text order	687	2.76
2	Left to right	1306	48.85
3	Bottom to top	1301	48.65
4	Spiral out	1025	34.82

The column bars shown below in figure 19 summarize the results of percentage improvement of machining time of GA over ArtCAM techniques. From this figure, it can be concluded that the percentage improvement of machining time is increased with a case of higher nodes population which take more machining time.

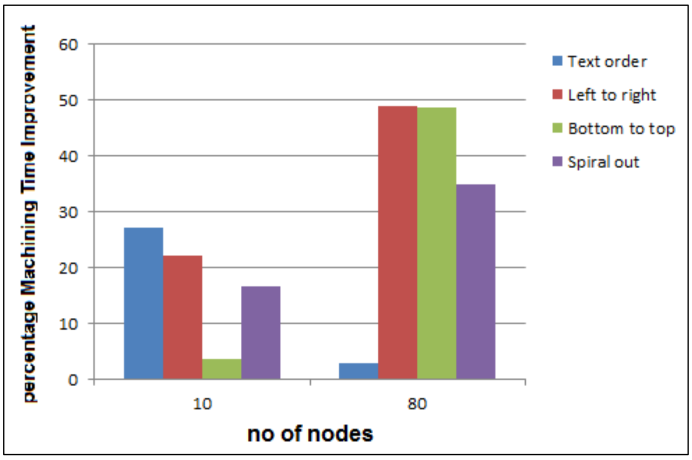


Figure 19. Percentage improvement of machining time of GA over ArtCAM techniques .

9. Conclusion

Minimization of non-productive time of tool during machining for drilling a group of holes significantly reduces the machining time. In the present work, GA technique is used with TSP and proved with results its performance in finding the optimum shortest path for the points to be machined, this performance is noticed clearly in problems of large number of points, where the machining time improvement in some cases reached nearly to 50% .

10. Suggestion for Future Works

Using another technique in finding the optimum shortest path such as ant colony optimization (ACO) or particle swarm optimization (PSO) which are more quick than genetic algorithm (GA) in finding the optimum shortest path.

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