Optimization of Drilling Process Using Non-Conventional Method

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***Abstract*—Reducing time in the machining process is important in order to increase the efficiency of the process. In this present study, a non-conventional method was used to minimise the tool path length in the drilling process in order to decrease machining time. Ant Colony Optimisation (ACO) and Particle Swarm Optimisation (PSO) were applied to optimise the tool path in the drilling process. Then, the optimum tool path length was compared to the Genetic Algorithm and conventional methods. A workpiece with 158 holes was developed in Solidworks software in order to minimise the tool path length based on the drilling process. Then, the model was exported to Mastercam software for the simulation of tool path. The result of ACO and PSO showed that the optimisation process could reduce the tool path length in the drilling process as compared to the tool path length produced by Mastercam. It could be summarised that the simulation of non-conventional method is capable to determine the shortest tool path length, thus reducing machining time for the drilling process**

***Index Terms*—tool path length, Mastercam, particle swarm optimization, ant colony algorithm, drilling**

I. Introduction

Nowadays, drilling has become one of the important machining processes in the manufacturing industry. In a drilling process that is controlled by Computer Numerical Control (CNC), the parameter of the machining process is crucial in determining the efficiency of machining [1]. Several researches have focused on obtaining the optimum parameter of the drilling process to reduce machining time and surface roughness by using conventional methods such as [2][3][4]. For example, Aamir 2020 [5] has applied Taguchi method to determine the optimum parameters on two drilling processes, namely, one-shot drilling and multi-hole drilling.

By determining the optimum parameters such as cutting speed and axial depth, it can reduce the machining time and increase the efficiency of the machining process. Tool switch and cutting tool travel also influence the machining time in the drilling process [6]. Other than that, Chatterjee 2016 [7] has proposed and developed an improved version of latest evolutionary approach known as Harmony Search (HS) algorithm in order to obtain the optimum parameter of drilling process which is spindle speed and feed rate. Then, several experiments have been conducted to verify the optimization results. As the results, the relative error between the simulation and experimental result is 10%.

Besides, rather than focusing on the parameters of machining, the machining time in the drilling process can be reduced by minimising the tool path length. Non-conventional method can be used to minimise the tool path length, as it can decrease the machining time. Non-conventional methods have been used due to drilling that involves a large number of hole-making and tool sequence constraint. For example, [8] [9] [10] [11] used the Ant Colony Optimisation method to minimise the machining time in the drilling process. Besides, Genetic Algorithm is one of the conventional methods that has been used to minimise tool path length and machining time in the drilling process [12][13][14]. The tool path length is reduced by determining the sequences of cutting tools in drilling each hole in workpieces. Hence, Dalavi 2018 [15] has developed a new algorithm known as shuffled frog leaping with modification for the determination of optimal sequence of operations. In this study, the simulation is focusing to reduce total non-productive time and tool switch time of hole-making operations. The algorithm has been applied on six different problems of holes. To validate the algorithm, the obtained results are compared with dynamic programming (DP), ant colony algorithm (ACO), and immune based evolutionary approach (IA). Based on the

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comparison the modification of shuffled flog leaping algorithm is capable to determine the minimum sequence of operation in hole making operation.

There are other methods that also focus on minimising machining time, namely Particle Swarm Optimisation (PSO) [16][17] and Cuckoo search (CS) [18]. [16] has applied the PSO algorithm on 15 test drilling problem in order to reduce machining time by minimizing the tool movement and tool switching. They have found that optimization process based on PSO is reducing the machining time about 70%. Besides, a new version of PSO has been developed by [19]Zhang 2011. By using the new version, algorithm has been able to converge on the global optimization solution with the method of generating the stop evolution particle over again. The new version of PSO has been tested on four different problem which is on two drilling problems and two cases of travelling salesman problem (TSP). The performance comparison shows that the PSO algorithm with global convergence characteristics based on order exchange outperforms the other versions of PSO in solving sequence optimization problem.

Karruppanan 2019 [20] also develop a new method to minimize the sequence cutting in CNC machine bay using PSO. Based on simulation and verified experiment, the application of PSO was satisfactory and produce machining time about 40%. Another AI method such as bat algorithm also has been applied to determine the optimal path sequences for drilling process [21]. There are four models of drilling has been used to determine the machining time, machining cost and non-productive cost. Bat algorithm is one of new algorithm based on nature inspired developed by [22]Yang 2010. The results obtained has been compared with others AI method which is GA, ACO, PSO, and Artificial Bee Colony (ABC). Based on the simulation, it has been concluded that BA outperforms the other algorithms with respect to the computational speed and variability in the derived drill path lengths. In order to optimize the tool path length and machining time, the algorithm has applied the TSP. To develop the mathematical model of the drilling process, several researches applied the concept of Travelling Salesman Problem in order to determine the minimum tool path length [23][24][25]. Generally, there are several AI methods has been applied in minimizing the performance of machining process. Therefore, [26]Bharat 2018 has produced a review details on optimization on machining process using Artificial method. They have concluded that in minimizing machining time, the ACO method is most capable method compared to GA, PSO, and Arificial Neural Network.

Based on the study presented by [23], the total machining time spent to drill the holes in a workpiece was around 40% to 80% depending on the number of holes and shape of workpieces. Therefore, it is important to optimise the machining process in order to decrease machining time. In this present study, the optimisation process applied non-conventional methods, namely Ant Colony Optimisation (ACO) and Particle Swarm Optimisation (PSO), to minimise the tool path length of the drilling process. Then, the result of tool path length was compared with other non-conventional and conventional methods presented by [11] and Mastercam software, respectively.

II. METHODOLOGY

In order to study the efficiency of ACO and PSO methods in minimising the machining process, a rectangular workpiece with dimensions of 60 mm x 100 mm x 10 mm was modelled using Solidwork software. There were 158 holes with 10 mm of depth on the workpieces. Figs. 1 and 2 show the three dimensional (3D) and top view models of the workpieces. These workpieces were modelled based on the study by [11]. Each node of holes was represented by a coordinate denoted by x and y coordinates in x and y axes, respectively.

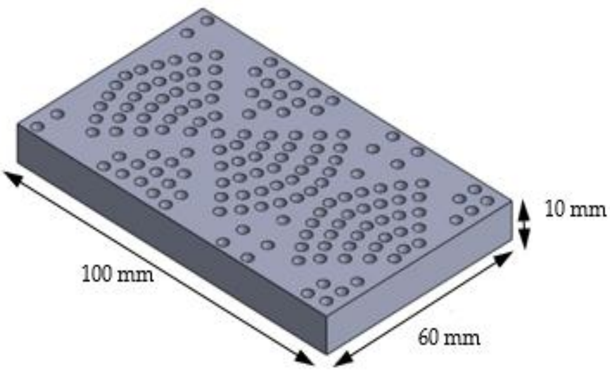


Figure 1. Three-dimensional model (3D)

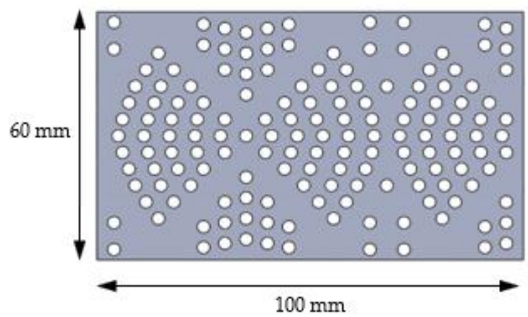


Figure 2. Top-view of model

In order to reduce the machining time for hole-making operations, ACO was used to minimise the tool path length as reduction in tool path length would in turn decrease the machining time for the drilling process. The ACO method is one of the evolutionary methods based on the movement of ants in search for food. Hence, the optimum tool path length is determined based on the movement of ants from one node to the next node. Equation 1 was used to determine the movement of ants. The ants were placed on n nodes, and they moved from node i to node j by using an equation called rule arbitrary probability.

$$P_{i,j}^{k}(t) = \frac{[\tau_{i,j(t)}]^{\alpha}[\eta_{i,j}(t)]^{\beta}}{\sum_{t\epsilon N_i^k}[\tau_{i,j}(t)]^{\alpha}[\eta_{i,j}(t)]^{\beta}}\ j\epsilon N_i^k \tag{1}$$

Where is:

N_i^k	= list of nodes, were not visited by ant
τ _(i,j) (t)	= intensity of trail on edge (i,j) at time
α	= weight of the trail
η _(i,j) (t)	= 1/dij is called the visibility
β	= weight of the visibility

The ants were placed randomly on each hole, and their movement to another hole was influenced by the value of pheromone trail (α) or the distance between each hole (β). Once all ants had completed their own loop, the pheromone would be updated on all vertices according to the global updating rule, and the shortest distance would be determined. This process was continued until the maximum iteration set was met. The flow process of ACO applied in the drilling process is as shown in Fig. 3.

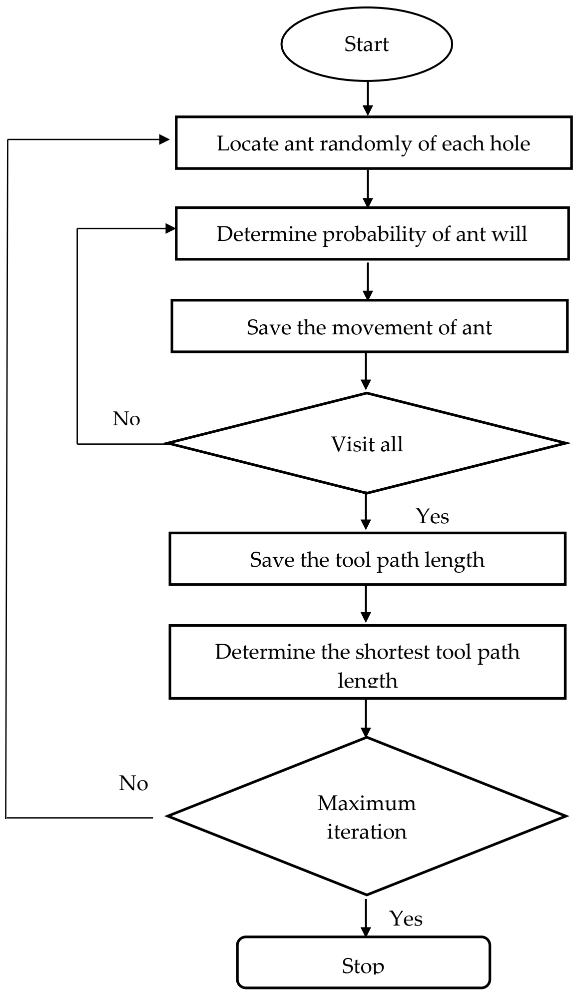


Figure 3. Flow process of ACO

PSO is classified as swarm intelligence, inspired by the behaviour of a flock of birds and fish movements. While searching for food, birds are either scattered or go along until they find a place where they can get food. While the birds are looking for food from one place to another, there is always a kind of bird that can smell the food very well, i.e. birds that are able to detect where food is available and have better food resource information. As they transmit information, especially information that is good at any time when looking for food from one place to another, conduced with good information, these birds will ultimately flock to places where food is available. The parameters of the PSO algorithm that are commonly used are inertial weight, acceleration factors (c_1 and c_2), population size, maximum size, maximum iteration, and initial velocity. By stopping the process, the best accomplished solution, or sequential representation of the possible order of execution of drilling, according to the assigned number of holes displayed. Termination criterion is defined by the number of iterations. The flow process of PSO applied in the drilling process is depicted in Fig. 4.

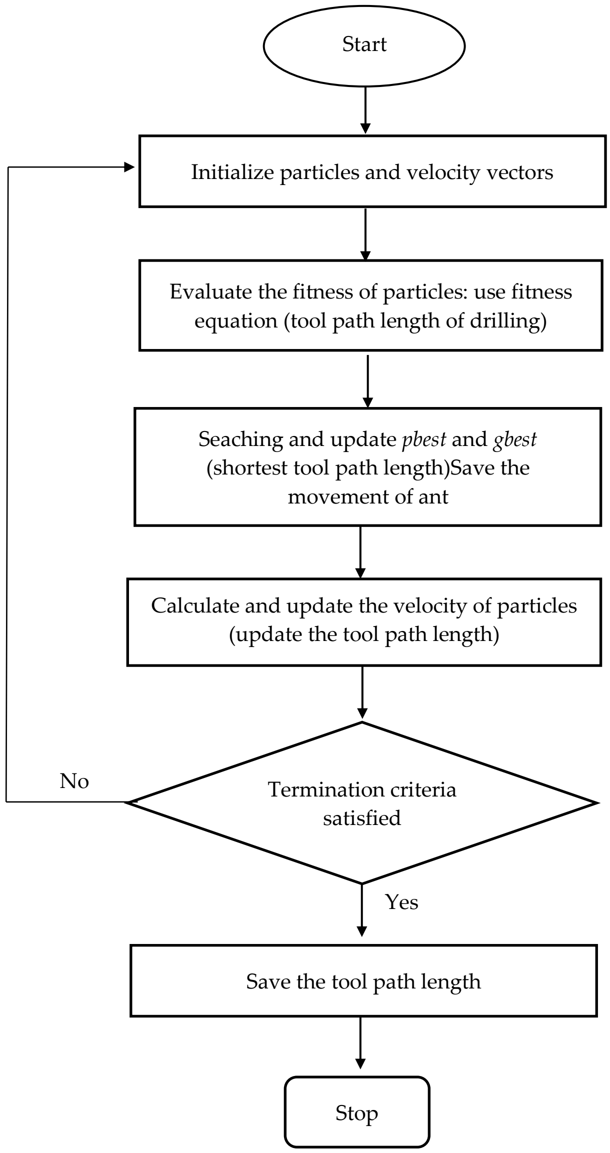


Figure 4. Flow process of PSO

III. Results and Discussion

The simulations of ACO and PSO were performed in Matlab software. For ACO, each simulation was repeated five times based on different numbers of ants, which were 30, 60, 90, 120, and 158. Number of ants was determined based on the number of holes. The values of α and β were 5 and 4, respectively, and the number of iteration was 1,000. For PSO, several parameters were determined before running the simulation, namely the upper limit, lower limit, number of particles, and number of iterations, and their values were 0, 1, 10, and 1000, respectively. Fig. 5 shows the optimum tool path route optimised by ACO, while the results of tool path route of PSO are shown in Fig. 6. Based on both figures, it is shown that PSO was capable of producing shorter tool path length in the drilling process, which was a decrease of 2.5% as compared to the ACO method. Besides, the tool path route based on PSO was more efficient than ACO. A study conducted by [27] found that PSO was capable of producing efficient results and provided better performance as compared to ACO due to the local searching of PSO.

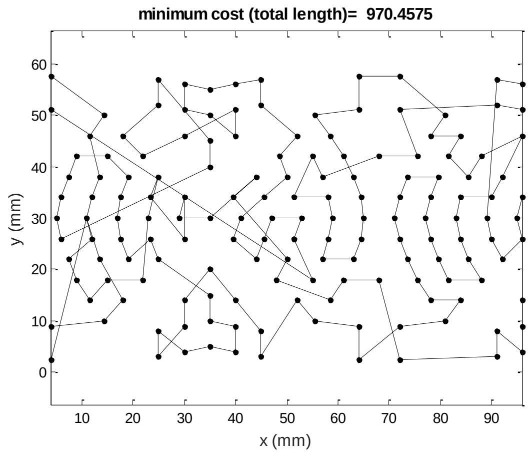


Figure 5. Tool path length of drilling based on ACO

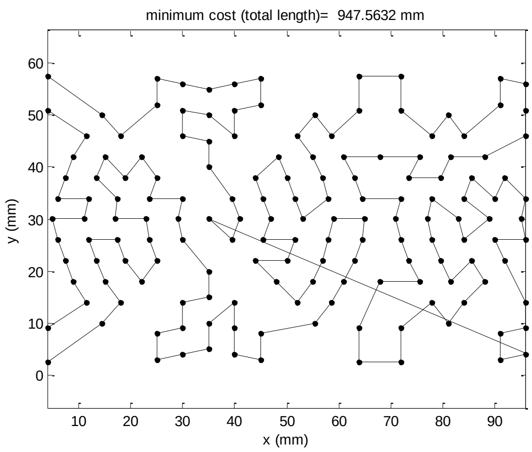
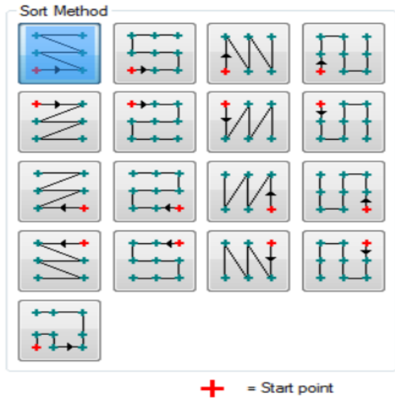
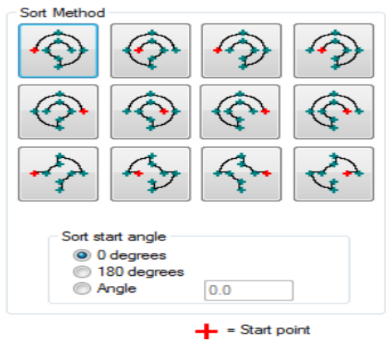


Figure 6. Tool path length of drilling based on PSO

To study the performance of ACO and PSO methods, this study also compared the tool path length with other non-conventional and conventional methods. Mastercam software was used to simulate the tool path length of the drilling process. In Mastercam, several methods were employed for the drilling operation in order to determine the tool path length. There were 15 methods of tool path applied in Mastercam as show in Fig. 7 and the overall results are depicted in Table I.



(a)



(b)

(c)

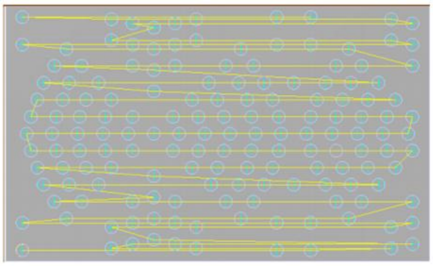
Figure 7. Sorting method (a) 2D sort (b) Rotary sort (c) Cross sort

TABLE I. Results of Tool Path Length and Machining Time in Mastercam

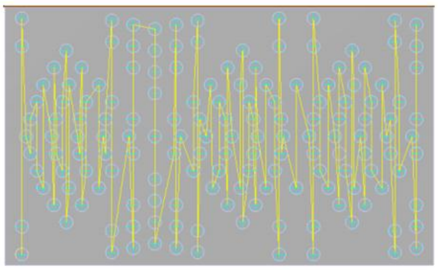
Nu.of simulation	Sort method	Feed Path Length (mm)	Rapid path length (mm)
1	X+ Y+	1580	4744.15
2	X ZIG+ Y+		3702.73
3	Y+ X+	1580	4198.62
4	Y ZIG+ X+	1580	3732.01
5	X+ Y-	1580	4744.15
6	X ZIG+	1580	3702.73
7	Y- X+ 1580 4214.406	1580	4214.40
8	Y ZIGX+	1580	3732.01
9	X- Y+	1580	4744.15

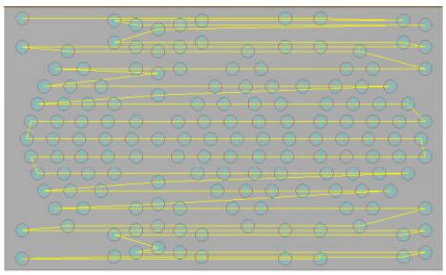
10	**X+ ZIGY+**	**1580**	**3648.82**
11	Y+ X-	1580	4214.40
12	Y ZIG+ X	1580	3747.79
13	X- Y-	1580	4744.15
14	**X- ZIGY-**	**1580**	**3648.82**
15	Y- X-	1580	4198.62
16	Y ZIGX	1580	3747.79
17	POINT TO POINT	1580	3747.79
18	CW R-	1580	4731.21
19	CW R+	1580	4731.21
20	CW Z-	1580	4731.21

According to the result, the shortest tool path length was obtained by using a method of X+ ZIGY+ and X- ZIGY-, which was 3648.22 mm. Fig. 8 illustrates the shortest tool path length generated by Mastercam software. Summary of results of tool path length based on different method: ACO, PSO, Genetic Algorithm (GA), and Mastercam software is depicted Table II. The results of GA was obtained by a study presented by [28]. The shortest tool path length (average) was 947.5632 mm based on the PSO method. The results obtained were similar with the results gained by [29] and [30], in which PSO produced more accurate results. However, these results depended on the shape of workpieces and complexity of the drilling process. Based on a study performed by [23], ACO was capable of producing better performance as compared to PSO and GA. However, the shortest tool path length is obtained by using method of X+ ZIGY+ and X- ZIGY- which is 3648. 22 mm.



(a)





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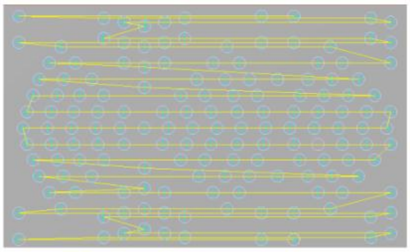
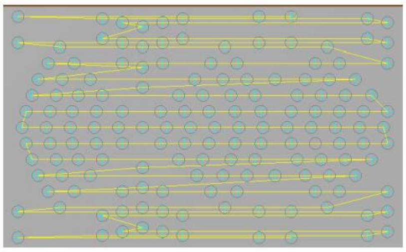


(d)



(e)

Figure 8. Tool path based on sorting method in Mastercam (a) X ZIG+ Y+ (b) Y ZIG+ X+ (c) X ZIG+ Y- (d) X ZIG- Y+ (e) X ZIG- Y

TABLE II. COMPARISON OF TOOL PATH USING SEVERAL METHODS

Methods	Total path length, (mm)
ACO	970.4575
PSO	947.5632
GA	1108.1375
Mastercam	2707.529

Based on the Table II, the shortest tool path length is obtained by using ACO method. Fig. 9 shows the tool path generated based on ACO that simulate is Mastercam.

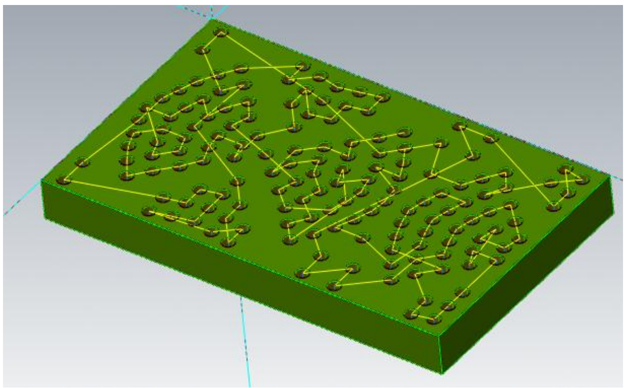


Figure 9. Tool path based on ACO generating in Mastercam

IV. CONCLUSION

This paper presented a study to minimise tool path length in order to decrease the machining time in the drilling process. ACO and PSO were employed to study the performances of both methods on producing shorter tool path length. Then, the results of tool path length were compared with GA and conventional methods. Based on the simulation results, it can be ascertained that the PSO method performed better as compared to ACO, GA, and

Mastercam software in generating shorter tool path length. However, these techniques need to be further explored to find their suitability to certain applications.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

This research is contributed by Haslina and Mohamad Shukri which is focusing on simulation work and writing the paper. Norfazillah and Lee analyzed the data and Aslinda contributing in checking the results and grammar. All authors had approved the final version.

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