Optimization of Tool Path Length on Three-Dimensional Drilling Application Using Ant Colony Algorithm

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Abstract. The lower machining time is important characteristic in the drilling machining process. Drilling process costs will increase if the machining time is high. Therefore, the main objective of this research is to develop Ant Colony Algorithm (ACO) to reduce the machining time by obtain the optimal tool path length. By using this algorithm, it can minimize the tool path length and significantly decreasing the machining time of drilling process. Simulating in 3-dimensional drilling on ACO has been constructed to minimize the shortest path of the drilling process. There are two type of workpiece has been used, which is simple block with 10 holes and complex block design that has 154 holes. ACO algorithm has been developed in Matlab R2017b to determine the optimal parameters of ACO of tool path length in drilling. Besides, simulation also has been done to investigate the effect of ACO parameter which is weight of pheromone ($\alpha$), weight of trail ($\beta$), evaporation coefficient ($\gamma$), and number of iterations. As a result, by define the parameter of iteration number at 900, the optimum parameter of weight of pheromone ($\alpha$) is 5, weight of trail ($\beta$) is 4 and evaporation coefficient ($\gamma$) is 0.4. Based on these parameters, the minimal tool path length obtain for simple and complex model are 286.965 mm and 6770.9860 mm respectively. Then, the result of tool path length of ACO simulation has been compared with the Mastercam outcome. ACO achieves a total tool path length of 286.965 mm while Mastercam achieved 569.878 mm for simple block design. Meanwhile, for complex block design, ACO produces a total tool path length of 6770.9860 mm while Mastercam has generate 55828.9050 mm of tool path length. By comparing these two approaches, ACO and Mastercam, ACO has that the short total tool path length by 49.64% on simple block design and 87.87% for complex block design.

1. Introduction
The rapid development of drilling process has experienced transition from time to time. This transition has been possible due to the technological advancement in drilling. Nowadays, drilling has become a very important process in industries. Drilling is a cutting process that uses a drill bit to cut a hole in solid materials with a circular cross section. The drill bit is often a multipoint rotary cutting tool. The bit is pressed against the piece of work and rotated at rates between hundreds and thousands of revolutions per minute [1]. There are many studies has been done in order to increase the efficiency and production of drilling process, such as by doing optimization of drilling process [2,3].
Optimizing the tool path has played an important role, especially in mass production because reducing the time taken to produce one piece eventually leads to a substantial reduction in the cost of the entire series [4]. Many methods of artificial intelligence (AI) or hybrid optimization have been adapted in various studies by researchers such as genetic algorithms (GA) [5], artificial neural networks (ANN) [6], particle swarm optimization (PSO) [7], and ant colony optimization (ACO) [2,3]. The main objective of this study is to find the best tool path route in drilling process to reduce the machining time. Based on Abdullah et al. [8], ACO is one of the methods that capable to obtain the optimal result in term of tool path length. Therefore, in this paper, a study has been conducted to optimize the tool path length in drilling process which focus to three-dimensional drilling process.

On the previous study by Haslina 2020 [2], the optimization of drilling is focusing on two-dimensional model. Hence, this paper focuses on the development of the algorithm Ant Colony Optimization (ACO) for use in the search for the optimal tool path length for 3-dimensional drilling process simulation and to determine the best parameters in drilling process on Ant Colony Optimization (ACO). The result of this study also is compared with Mastercam. With this algorithm, it can optimize the drilling process thus enhancing the productivity and efficiency.

2. Methodology

There are two types of workpiece used has been developed which is, simple block with 10 holes while the dimensions measures are 60 mm x 100 mm x 15 mm and complex block design that has 154 holes with dimension of 315 mm x 715 mm x 300 mm as shown in Figure 1. Complex block design workpiece was developed based on suggestion in his research [9]. This two-design workpiece was designed using Solidwork 2018 software. This workpiece style has a random coordinate but, is set in place for the holes. The drilling tools will follow their radius size of the holes which is 5 mm each to ensure the procedure was performed correctly.

![Figure 1. Three dimensional drilling model (a) simple (b) complex.](image)

2.1 Ant Colony Optimization

The Ant Colony Optimization (ACO) is a probabilistic method used to overcome computer problems that can be reduced to finding good trajectories by using graphs for computer science and organizational analysis. Artificial Ants are multi-agent methods that are inspired by real ants’ actions. The pheromone-based communication of biological ants is often the predominant paradigm used [5]. Multiple optimization tasks including some type of graph, e.g. vehicle routing and internet routing, have been used for combining artificial ants and local search algorithms. The first algorithm was originally proposed by Marco Dorigo in his doctoral thesis in 1991 [10] to find an optimum path on the basis of ants seeking a road between the colony and a food source. The original idea has since diversified in
order to solve a wider range of mathematical problems, and therefore there have been several problems that draw attention to several aspects of ants’ behavior. ACO carries out a template-based search from a broader perspective and shares some parallels with distribution algorithm estimations [5]. The first ACO algorithm was named the ant method and aimed at solving the problem of traveling salesman (TSP), in which the objective is to find the shortest round trip to connect several cities. The general algorithm is straightforward and based on a collection of ants, each making one of the possible city round trips. At each stage, the ant chooses to move from one city to another according to some rules:

i. It must visit each city exactly once.
ii. A distant city has less chance of being chosen (the visibility).
iii. The more intense the pheromone trail laid out on an edge between two cities, the greater the probability that that edge will be chosen.
iv. Having completed its journey, the ant deposits more pheromones on all edges it traversed, if the journey is short.
v. After each iteration, trails of pheromones evaporate.

Moreover, with time, the pheromone traces on each route will decay. If there has been no pheromone applied to a path for a certain time, the pheromone density would decrease to zero. The decline in pheromone quality will also help ants find the shorter path faster for the pheromone on the longer paths receiving less pheromone, and their faster pheromone decline will make it less appealing to ants. As shown in Figure 2 are the steps of pheromone trails:

i. An ant chooses a path among other and lay a pheromone trail on it.
ii. All the ants are travelling some paths, laying a trail proportional to the quality of the solution.
iii. Each edge of the best path is more reinforced than others.
iv. Evaporation ensures that the bad solutions disappear.

![Figure 2. The pheromone trail of ant.](image)

Problems that occur in drilling such as the tool path length and the time taken for machining process can be solved by adapting the ACO algorithm. It is because ACO algorithm can play a role in solving the problem of drilling path optimization [11]. Due to ACO is a population-based on optimization approach, it has been used to solve the combination optimization problems effectively. The approach is a simulation based on the behavior of ant that involves searching the shortest routing for the tool path length in drilling process. When drilling process is start, ACO would suggest the best routes for the drill bit to follow as the tool path length. Hence, the shortest distance would be picked in order to reduce the machining time. The ACO approach used in this research to find the optimal tool routing path \( L \) is based on the Equation (1).
Where:

- $x$ is the first coordinate of the hole for x-direction
- $y$ is the second coordinate of the hole for y-direction
- $z$ is the first coordinate of the hole for z-direction

\[ L = \sum \sqrt{(x^2 - x_1) + (y^2 - y_1) + (z^2 - z_1)} \]  \hspace{1cm} (1)

2.2 MasterCAM Simulation

The simulation of drilling has been done based on conventional method is Mastercam to compare the results of optimal tool path length. In this simulation, it is start with change the format of the workpiece’s file from Solidwork 2018 to step format. It is because this file would be run in Mastercam software. Next, select the machine type, then select mill, and then select default. Furthermore, select Tool paths and then select drill, After that, insert the parameters which need in the machine properties. In this simulation three important machining parameters are cutting speed, feed rate and cutting depth [12,13].

The next step is set the drill bits for drilling process, the diameter for the size and other require dimensions. The tool path can be found by automatic sorting method after all the parameters and dimension are inserted. Next, select all the operations, regenerate and verify selected operations. To determine the total tool path length in Mastercam, the method that used is cross sort, that include sorting method which are CW ZIG Z-, CW ZIG Z+, CCW Z-, CCW Z+, CCW ZIG Z-, CCW ZIG Z+, Z- CW, Z+ CW, Z- CCW, Z+ CCW, ZZIG- CW, ZZIG+ CW, ZZIG- CCW, ZZIG+ CCW.

In order to verify the simulation results of ACO, the tool path length obtained based on ACO will be compared with tool path length on Mastercam. The Equation 2 is used to observed the reduction of tool path length between ACO on Matlab and Mastercam simulation based on the total tool path length result on simple block design and complex block workpiece [8]. By using this formula, it can show if ACO brings efficiency in terms of tool path length on drilling process or not compared to traditional drilling process.

\[ TL = \frac{ACO (TL) - Mastercam (TL)}{ACO (TL)} \times 100\% \]  \hspace{1cm} (2)

3 Results and Discussion

Ant Colony Optimization (ACO) simulation has some of parameter that can be studies to determine the shortest path of the workpiece block. The effect of parameter variable has been studied to determine the effect on the total length of the tool path. The parameters picked are number of iterations, weight of pheromone $\alpha$, weight of trail $\beta$ and evaporation coefficient $\epsilon$. To ensure the accuracy of the ACO algorithm, it can be studied how these parameters could effect on the results of the tool path length. Consequently, the changes in the parameters are possible and can be discussed to ensure that the results of our simulation are valid and approved. Following this study, study explains the importance and efficacy of the coefficient of evaporation in drilling processes based on the objective of this study to investigate the impact of the parameter on ACO in drilling processes. To solve this objective, we still used a complex design block with 154 holes to be tested with different values for the evaporation coefficient $\epsilon$ parameters. The shortest total path length is obtained from evaporation coefficient $\epsilon$ set at 0.4 in accordance with Table 1. If pheromone $\alpha$ weight is set at 5 and weight of trail $\beta$ is set at 4 and evaporation coefficient $\epsilon$ is set at 0.4, it is showing the shortest length relative to other parameters at 6894.2709 mm.
Table 1. Effect of evaporation coefficient.

| Evaporation coefficient, $e$ | Weight of pheromone, $\alpha$ | Weight of trail, $\beta$ | Total path length (mm) |
|-----------------------------|-------------------------------|--------------------------|------------------------|
| 0.1                         | 5                             | 4                        | 6943.7887              |
| 0.2                         | 5                             | 4                        | 6958.1726              |
| 0.3                         | 5                             | 4                        | 6926.8470              |
| 0.4                         | 5                             | 4                        | 6894.2709              |
| 0.5                         | 5                             | 4                        | 6904.8844              |

3.1 Toolpath Length Analysis

To achieve the main objective of this analysis, a comparison of the tool path length was made between the result from the Ant Colony Optimization (ACO) algorithm and result from Mastercam. The relation has to be made to assess the ACO algorithm's performance too. The total length of the tool path obtained by the ACO algorithm for simple block design workpiece is 286.9650 mm, Mastercam achieves the best total tool path length of 569.878 mm. For complex block design workpiece is 6770.9860 mm while Mastercam achieves the best total tool path length is 55828.9050 mm. To evaluate the efficacy of the ACO algorithm, the Equation 2 has been used. By this calculation, it is proven that in comparison with Mastercam, ACO has that the total tool path length by 49.64% for simple block workpiece design while 87.87% for complex block workpiece design.

4 Conclusion

In this research, ACO has been develop using Matlab to simulate the tool path length in drilling process. The main purpose is to reduce the machining time of drilling process. ACO algorithm has been developed in Matlab to minimize the length of the tool path in drilling process. ACO's simulation results based on 154 holes based on complex geometry block and simple block design with 10 holes. For the optimization using ACO, the parameters concerned in this analysis is the number of iterations, pheromone weight $\alpha$, weight of trail $\beta$ and evaporation coefficient $e$. For this analysis, the optimal of parameter is 900 number of iterations, weight of pheromone $\alpha$ is 5, the weight of trail $\beta$ is 4 and the coefficient of evaporation $e$ is 0.4. Then, comparing simulation tool path length in drilling operation using Ant Colony Optimization (ACO) and Mastercam. Mastercam achieves a total tool path length of 569.878 mm on simple block design while 55828.9050 mm for complex block design. Meanwhile, ACO generate best tool path with 286.965 mm for simple block design and 6670.9860 mm for complex block design. By comparing these two approaches, it is shown that in comparison with Mastercam, ACO has that the total tool path length is 49.64% for simple block design and 87.87% for complex block design.

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