Comparative Study of Non-Productive Tool Path Length for Contour Parallel Machining

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ABSTRACT

Reduction of machining time is significant for increasing the efficiencies of a machining process. It can be minimized by the rise with the cutting speed or decrease the tool path length. This paper presents an optimization method of non-productive tool path length during contour parallel offset machining by minimizing the tool retraction based on Ant Colony Optimization (ACO). The optimization of the tool retraction is modeled as an application of the Travelling Salesman Problem (TSP). To assess the performance of the proposed method, the length of the non-productive tool path obtained by ACO is compared with traditional computer-aided manufacturing (CAM) software. It can be ascertained that the ACO method generates a non-productive tool path length that is approximately 20% better than the conventional method..

Keywords: *Tool Path Length, Contour Parallel, Ant Colony Optimization, Pocket Machining*

ISSN 1823- 5514, eISSN 2550-164X

Received for review: 2016-09-25
Accepted for publication: 2017-03-03
Published: 2017-07-01

Introduction

In today's global challenge in new-product development, pocket machining of complex shapes has experienced special attention from many researchers. Usually the key element in deciding the efficiency of pocket machining is the capability to minimize the complete machining time [1], which consists of productive and non-productive time (NPT). The time whilst tools are absolutely cutting a work piece is specified as productive machining time; the rest of the time during tool repositioning is known as NPT or airtime. Most studies of minimizing the machining time have focused only on minimizing productive machining time but not the NPT [2]. For instance, Ahmad et al. [3], Palanisamy et al. [4], Li. et al. [5], Kumar & Garg [6], and Prakash et.al. [7] suggested an optimization of machining parameters in a milling machine by minimizing the cutting time using genetic algorithms (GA). GA is a technique is often adapted for the cutting process such as, milling, lathe [8]. It can handle diverse types of problems for cutting optimization such as, machining time, material removal rate, and the cutting conditions during machining.

Unlike others, Yildiz [9], proposed a hybrid optimization approach based on a differential evolution (DE) algorithm, and cuckoo search algorithm (CS) for reducing the production cost and machining time of the milling process. The desirable parameters obtained from the optimization are used in a computer numerical control (CNC) machine to enhance machining effectiveness. It seems that maximizing the whole profit rate of milling operation can be obtained by these algorithms, which presented better results than GA and ACO. However, the profit rate obtained based upon the DE algorithm is larger than CS. In addition to cutting parameters, the machining strategies are also a very significant factor. Kim & Choi [10] and Azeem [11] proposed a machining time model for different types of tool path strategies such as contour parallel offsets and parallel zigzag. A comparison of these strategies proved that contour parallel strategies provided lower tool path lengths than parallel zigzag strategies. The reduction shortened the machining time. Additionally, rough machining times for high speed milling have been evaluated by Hbaieb et al. [12] based in a time model that consists of the time of movement during work at a rapid rate, the time required to change tools, the time for tool loading, and auxiliary time. Although the value of cutting parameters used throughout the experiment was not optimum, the time modeling has successfully computed the machining time in a straightforward way.

NPT also impacts the performance of machining processes. In most situations, it consumes 15 to 30% of total machining time [13][14]. Therefore, minimizing the NPT is substantial to increase the effectiveness of the machining process. Castelino et al. 2002 [13] developed an algorithm for minimizing NPT or airtime for milling process by applying connected distinctive tool path segments. The algorithm concentrated on pocketing process with utilization of multiple types of cutting tool. Each pocket is represented as a cell which comprised nodes of each segment of contour parallel tool path. This problem is formulated as generalized traveling salesman problem (GTSP). In GTSP, *n* cities are grouped into *m* clusters. With this method, each node on the cell is expressed as cities and known as clusters. GA is adapted to unite the node from each cell to another cell in order to obtain the minimum airtime motion. In different case, Yang et al. 2010 [15] also applied GTSP for multi contour pocket to optimize the tool-path airtime using GA, SA and hybrid of GASA.

Oysu & Bingul 2009 [14] has developed an algorithm based on hybrid of genetic algorithm and simulated annealing to reduce the machining by optimized non-productive tool path length for 2.5D machining. The tool path length is computed as distance between point retraction of each contour. With this hybrid algorithm, the performance of SA has been improved with information provided by the GA algorithm. In addition, this algorithm can be applied to 3D sculpture machining problems very efficiently because there are too many tool retractions needed. Furthermore, Liu et al. 2011 [16] additionally applied hybrid of GA and SA to optimize the tool repositioning routes. However, in their case, the tool change times also considered in reducing machining time. Gupta et al. 2011 and Kumar et al. 2014 [2][17] optimized the NPT by reduce the tool retraction using GA and hybrid of GA. At the same they are also studied the effect of parameters in GA which effect the results of NPT. This algorithm is can be applied on 3D contour problems which are very essential in current scenario.

This paper presents an Ant Colony Optimization (ACO) based method for minimizing the non-productive tool path for pocketing with complex shape and different height of center of offset.

Contour Parallel of Pocket Machining

According to Kim & Choi (2002)[10], the contour parallel technique acquires less machining time since the cutting tool remains in touch with the workpiece and therefore, decreases idle time (Dhanik & Xirouchakis 2010)[18]. However, for multi-pocket machining with a complex shape, the process requires the cutting tool to retract many times during rough machining. Figure 1 shows a geometric example for more than one center offset contour. NPT lapses when the tool moves from one center offset to another. The prime influence in minimizing the non-productive motion is by optimizing the tool retraction length. In the contour parallel technique a single entry and retraction point for each segment of a contour is employed as illustrated in Figure 2. These entry and retraction points coincide with each other and represented by nodes, which are expressed by coordinates in the x and y directions, respectively. The cutting tool is moved from one center to another center of offset to cut the workpiece. These activities are known as tool retraction and lead to non-productive tool path length.

Generally, the machining time is determined by the following equation, which consist of complete, productive and non-productive as determined in Eq. (1)[2]:

$$T_m = \left[\frac{l_p}{(n.N.)_p} + \frac{l_{np}}{(n.N.f)_{np}} \right] \tag{1}$$

Where is:
l_p = length of productive time (mm)
l_{np} =length of non-productive time (mm)
n = spindle speed (rev/min)
N = number of flute
f = feed per tooth (mm/tooth)

In this paper, the non-productive tool path length and tool retraction time is optimised by minimising the distance between each node on each contour as in the following equation:

$$l_{np} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - yz_i)^2} + 2h \tag{2}$$

Where is h is represent the length of clearance height of cutting tool each time it goes up and down.

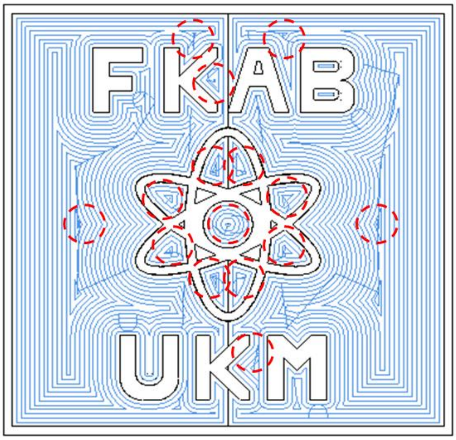


Figure 1: Center of contour parallel machining

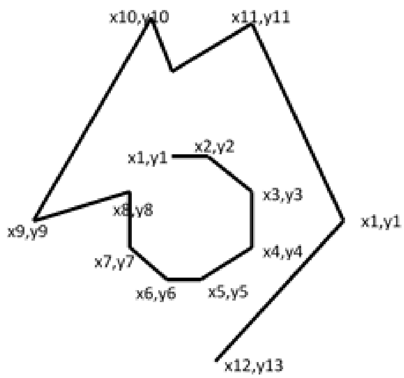


Figure 2: Tool retraction and entry node of each contour

Ant Colony Optimization

Dorigo and Stützle [19] applied the ACO method to the Travelling Salesman Problem (TSP) in obtaining the distance a salesman travels from one city to another. ACO method adapts a group of simulated ant movements in determining the shortest path between two places based on the pheromone level. Initially, ants *k* are placed on *n* cities; they move from city *r* to city *s* using an arbitrary probability rule as follows:

$$P_{r,s}^{k}(t) = \frac{\left[\tau_{r,s(t)}\right]^{\alpha}\left[\eta_{r,s}(t)\right]^{\beta}}{\sum_{t \epsilon N_r^k}[\tau_{rs}(t)]^{\alpha}\left[\eta_{r,s}(t)\right]^{\beta}} \; j \epsilon N_r^k \tag{3}$$

Where:

N_r^k	= list of nodes that have not been visited by ant *k*
$\tau_{r,s}(t)$	= intensity of trail on edge (*r,s*) at time t
α	= weight of the trail
$\eta_{r,s}(t)$	= $1/d_{rs}$ is called the visibility (d_{rs} represent the l_{np})
β	= weight of the visibility

Therefore, the concept of ACO is altered to contour parallel method of machining. The arbitrary probability rule is modified to determine how the cutting tool moves from one retraction to a following entry node. At the first iteration, ants *k* are placed randomly on m nodes. Each ant moves to the next node based on an arbitrary probability rule. Iteration continues until all ants complete the route, leaving pheromone trails on their paths. Subsequently, the minimum distance is determined, and the pheromone is updated with a global updating rule as in the following equation. This process repeated until the final iteration.

$$\tau(r,s) = (1-\rho).\tau(r,s) + \sum_{k=1}^{m} \Delta\tau_k(r,s) \qquad (4)$$

$$\Delta\tau_k(r,s) = \begin{cases} 1/L_k \ if \ (r,s) \ \in journey \ by \ ant \ k \\ 0 \qquad\qquad\qquad\qquad others \end{cases} \qquad (5)$$

ρ = evaporation rate
m = number of ants
$\Delta\tau_k$ = quantity of pheromone laid on edge k
L_k = length of the tour constructed by ant k

Results and Discussion

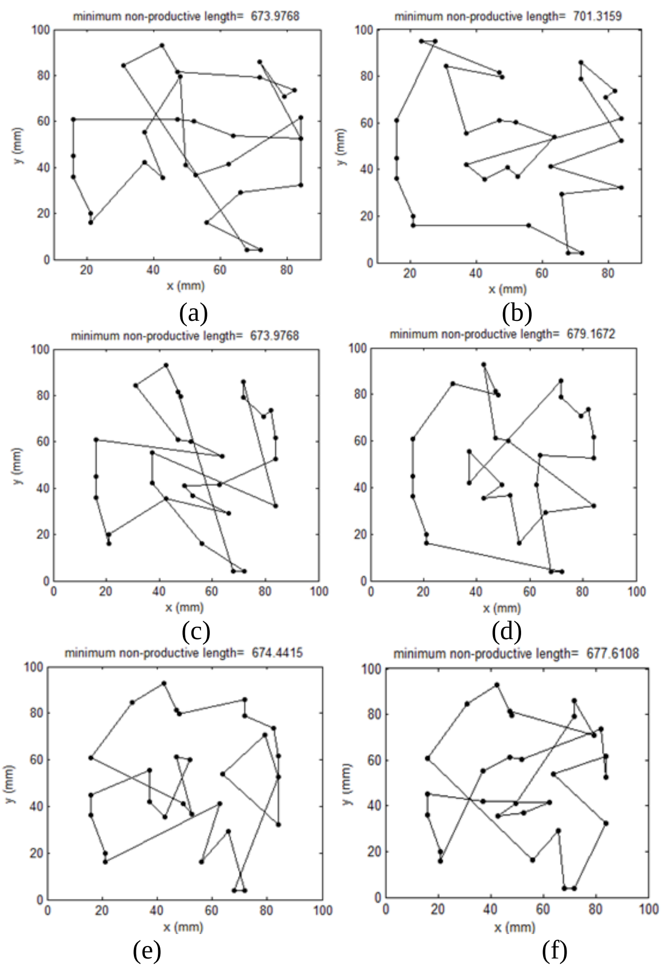
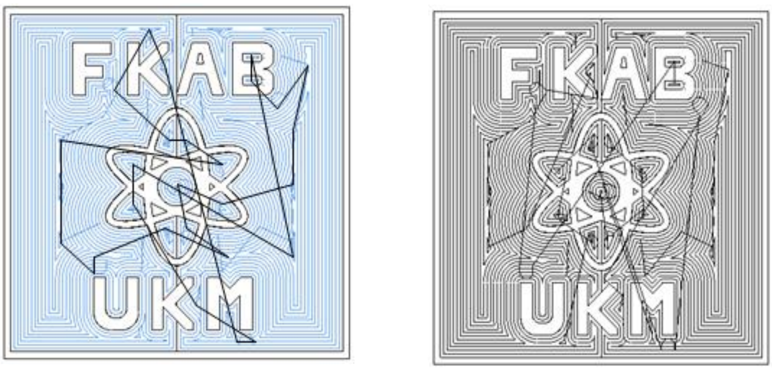


Figure 3: Simulation of non-productive length using ACO

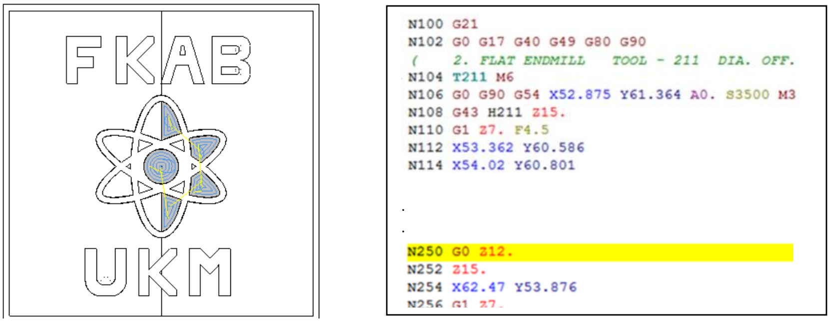
As illustrated in Figure 2, the coordinates are acquired located at the center of offset of each segment of pocket. Each coordinates is expressed by the *x*, *y* and *z* direction. To minimize the tool retraction, the non-productive length is defined as the distance between these centers of offset. Figure 3 shows the result of non-productive length based on ACO. The weight of trails and visibility is set as 3 and 5, respectively. Due to each ant is positioned randomly; the simulation is run for six times to obtain the optimal results. From the simulations, it was found the lowest non-productive length is 673.9 mm. While, the result attained using MasterCAM software is 842.6mm as shown in Figure 4.



(a) (b)

Figure 4: Comparison of non-productive length (a) Using ACO (b) Using MasterCAM

To monitor the effectiveness of the algorithm, G code will be generated by the MasterCAM software and will be transferred into the CNC machine. The G-code produced is formed by the CAM default system based on the contour parallel tool path. By using contour parallel, the movement of the cutting tool is in uninterrupted throughout the cutting process carried out. Throughout this process, the generated G1-code denotes as linear interpolation. To move from the first to the second part as shown in Figure 5(a), it will generate G0-code as a rapid movement. However, since the movement is generated by default from the software, sometimes it resulted in non-optimal rapid tool path solution which is also known as non-productive tool path length. Therefore, in this paper, ACO is used to perform the optimization on non-productive path length. To ensure the rapid movement of the cutting tool is similar to the result of optimization, the G-code should be modified as shown in Figure 5(b). In general, after the tool has finished cutting the first part, it will move to other parts by G0 as rapid movement and G1 as linear interpolation which is the movement to cut the workpiece.



(a) (b)

Figure 5: a) Rapid movement (b) Generating of G-code using MasterCAM

Conclusion

A new ACO-based optimization technique used for this study reduced non-productive tool path length 20% compared to the conventional method. Therefore, it was ascertained the proposed technique is comparable and useful in improving machining efficiency. However, this method needs to be improved by investigate the effect of parameters of the ACO output. Besides that, the experimental work should be carried out to ensure this optimization is to ensure the effectiveness of this algorithm

Acknowledgements

The authors are thankful to Ministry of Education Malaysia for supporting this study under grant FRGS/2/2014/TK01 /UKM/02/1

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