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MINIMIZING MACHINING AIRTIME MOTION WITH AN ANT COLONY ALGORITHM

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Abstract. *In machining operations, repositioning the cutting tool requires airtime motion of the cutting tool. Minimizing the airtime motion during pocket machining in mass production is important for increasing the efficiencies of the machining process. This paper presents an optimization of airtime motion during contour parallel offset machining by minimizing the tool retraction based on Ant Colony Optimization (ACO). Optimization of the tool retraction is modelled as an application of the Travelling Salesman Problem (TSP). To evaluate the performance of ACO, its result for the length of the non-productive tool path is compared with that of conventional computer-aided manufacturing (CAM) software. It is found that the ACO method produces a non-productive tool path length that is approximately 60% shorter than the conventional method.*
Keywords: Non-productive tool path length, Ant Colony Optimization, Pocketing

1. **Introduction.** In today's global competition in new product development, pocket machining of complex shapes has received special concentration from many researchers. Generally, the key factor in determining the efficiency of pocket machining is the ability to minimize the entire machining time by Hatna et al. [1], which comprises productive and non-productive machining time. The time when tools are actually cutting a work piece is defined as productive machining time; the remainder of the time during tool movement is known as non-productive time or airtime. Studies of minimizing machining time have focused only on minimizing productive machining time but not the non-productive time [2]. For example, Ahmad et al. [3], Palanisamy et al. [4], Li et al. [5], Kumar and Garg [6], and Prakash et al. [7] proposed an optimization of machining parameters in a milling machine by minimizing the machining time using Genetic Algorithms (GA). Parameters such as cutting speed, feed rate, axial depth, and radial depth were optimized; simultaneously, the surface roughness, cutting force, tool life, and amplitude of vibration were considered to be machining constraints. However, the disadvantage of the proposed GA method is that it can be applied to only a single objective optimization.

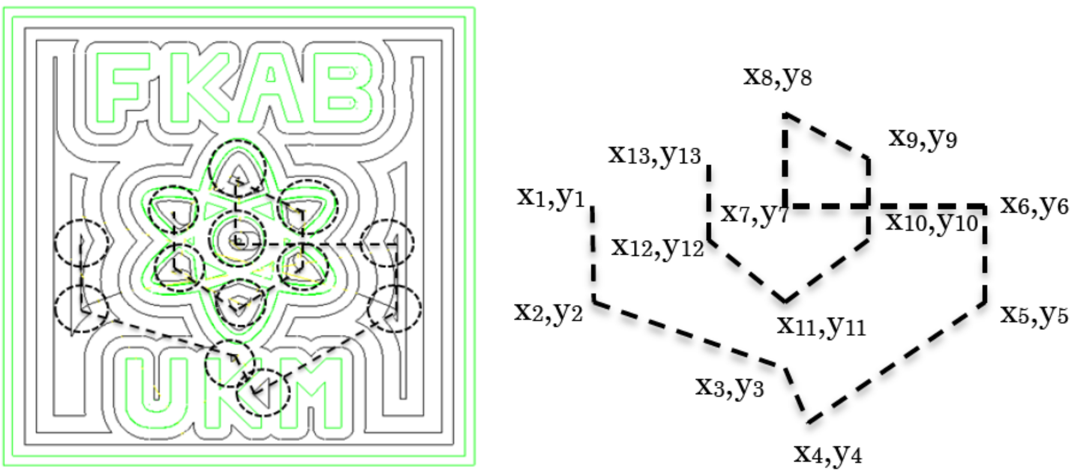
Non-productive time also influences the performance of machining operations. In most cases, non-productive time consumes 15 to 30% of total machining time [8,9]. Therefore, minimizing the non-productive time is important to increase the effectiveness of the machining process. Non-productive time can be minimized by reducing movement during cutting or tool retraction while machining. Hence, Oysu and Bingul [9] proposed a hybrid algorithm (hybrid-GASA) that is a combination of a Genetic Algorithm (GA) and Simulated Annealing (SA). With this hybrid algorithm, the performance of SA is improved with information provided by the GA algorithm. Additionally, Gupta et al. and Kumar et al. [2,10] minimized the tool retraction time in contour parallel machining with a Hybrid Genetic Algorithm (HGA) that was obtained by using a special heuristic method in the final sequence.

This paper presents a new method of minimizing the non-productive time in pocket machining by Ant Colony Optimization (ACO). The uniqueness of our method is the ability to reduce the cutting tool retraction to minimize the machining time even for a complex shape of multi-pocket machining. The paper is organized as follows: production time of pocket machining, new ACO method for pocket machining, result and discussion of the simulations and finally conclusion of the paper.

2. **Pocket Machining.** Figure 1(a) shows a geometrical example in which the geometry has more than one center-offset contour. Non-productive time elapses when the tool moves from one center offset to another. The key factor in minimizing the non-productive motion is by optimizing the tool retraction length. In the contour parallel method, a single entry and retraction point for each segment of a contour is employed as illustrated in Figure 1(b). These entry and retraction points coincide with each other and are represented by nodes, which are denoted by coordinates in the x and y directions, respectively. Generally, the machining time is determined by the following equation, which includes the total of productive and non-productive time.

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

where:
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)



(a) (b)

FIGURE 1. (a) Center offset of contour parallel machining; (b) entry and retraction point

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

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

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

$$P_{r,s}^k(t) = \frac{[\tau_{r,s}(t)]^\alpha [\eta_{r,s}(t)]^\beta}{\sum\limits_{t \in N_r^k} [\tau_{r,s}(t)]^\alpha [\tau_{r,s}(t)]^\beta} \quad j \in N_r^k \tag{3}$$

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
β = weight of the visibility

Therefore, the idea of ACO is adapted to the contour parallel method of machining. The arbitrary probability rule is adopted to resolve 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. Next, the minimum distance is determined and the pheromone is updated with a global updating rule as in the following equation. This process continues until the last iteration.

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

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

where:
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

In the ACO method, the selection of governing parameters is an essential task. In this study, the governing parameters that influenced our tool path length are the ants' populations, weights of trails, and weights of the visibilities. The trail weight α and visibility weight β influence the selection of the next city based on the ants' pheromone trail and the distance to the next node, respectively. The performance of ACO and the relationships of parameters to tool retraction can be determined by the probability rule in which each ant is placed randomly at a node and required to move a next node. Finally, a solution is achieved by each ant; it produces a non-productive tool path length for contour parallel machining.

4. **Results and Discussion.** The work piece used as an example in this paper contains 130 retraction nodes, which are represented by x and y coordinates as shown in Figures 2(a) and 2(b). The non-productive tool path length computed in a MasterCAM software

simulation using contour parallel techniques was 2290 mm. However, that tool path might not be optimal because it was generated using default software. Ant colony optimization was used to minimize the cutting tool travel.

The effects of ACO parameters on cutting tool retraction are shown in Figure 3. From Figure 3(a), it was found that the shortest non-productive tool path length was produced

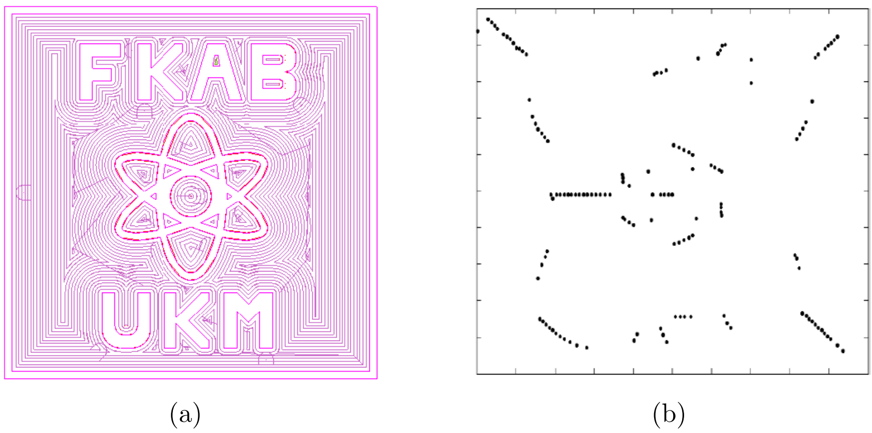


FIGURE 2. (a) Contour parallel tool path; (b) 130 nodes in contour parallel machining

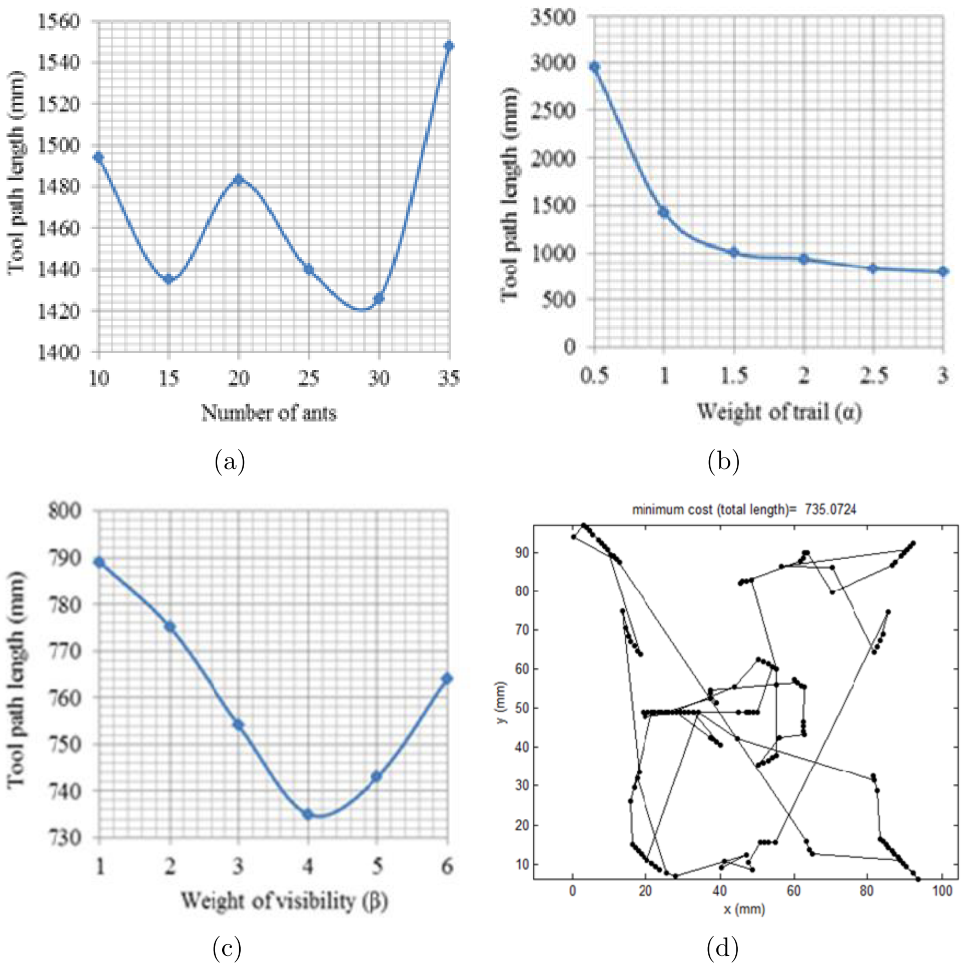


FIGURE 3. (a) Effect of number of ant; (b) effect of trail; (c) effect of visibility; (d) optimal result of ACO

by ant 30. For the effect of weight of trail, it can be observed that increasing the trail weight produces better sequences of tool retraction and decrease the non-productive tool path length. Figure 3(b) shows the increasing value α from 0.5 to 3 decreased the tool path length by 73%. The shortest non-productive length is produced by $\alpha = 3$. On the other hand, Figure 3(c) shows the effect of weight of visibility. Increasing β shortened the tool path length approximately 7%. The comparison with simulation by conventional method, using MasterCAM shows that the non-productive tool path length obtained was 2290 mm. The result of ACO is being compared with the help of relative percentage by relation defined as:

$$relative\ percentage = \frac{Conventional_{sol} - ACO_{best}}{Conventional_{sol}} \tag{6}$$

The ACO_{best} can be obtained by the shortest non-productive tool path length by running the multiple simulations based on different numbers of ants, weight of trail and weight of visibility. The shortest tool path length obtained was 735 mm based on 30 ants with $\alpha = 3$ and $\beta = 4$ as shown in Figure 3(d). It was found that ACO method can shorten the non-productive tool path length by approximately 60%.

5. **Conclusions.** In this paper, ACO has been applied to minimizing the non-productive tool path length for complex pocket machining. We can conclude that ACO is a suitable method for reducing the tool path length compared to the conventional method by using the suitable parameters of ACO. However, this method needs to be explored further, such as combining it with other AI methods to improve the ACO output.

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