Implementation of Ant Colony Optimization Algorithm to Minimize Cost of Turning Process

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Abstract. In machining process, turning is one of process that were significantly change by introduction of computer numerical control (CNC). However, the process improvement is not stopping there, but the focused has change to reduce the machining cost. Improper parameter selection will caused vibration in cutting, unsecure workpiece, unappealing finishing and cost consuming. Therefore, the optimum parameter setting is required because it related to certain quality characteristics such as the unit production cost. This paper presents the study to minimize production cost for CNC turning process by using Ant Colony Optimization (ACO). The result shows that, the ACO was capable to search for optimum production cost in shorter time compare to other methods, including Genetic Algorithm.

Introduction

In material removal process, turning is one of the oldest processes that were introduced to remove unwanted material by rotating the workpiece. Meanwhile, the cutting tool feeds into the rotating work piece and cuts away material in the form of small chips to create the desired shape [1]. The turning process were significantly change by introduction of computer numerical control (CNC) which made the process more accurate, easier and faster compare to conventional turning process. However, the process improvement is not stopping there, but the focused has change to reduce the machining cost [1].

In turning process, the parameter setting will affects a few independent variables such as surface roughness, cutting force, machining time, machining cost and so on. Improper parameter selection will caused vibration in cutting, unsecure workpiece, unappealing finishing and cost consuming [2]. Therefore, the optimum parameter setting is required because it related to certain quality characteristics such as the unit production cost.

Previously, a large number of researches have been done in finding the optimum parameter configuration for turning process. These works had implemented a wide range of approaches from classical to modern optimization techniques. For classical approach, [3] implemented Taguchi approach to determine optimal surface roughness on the turning process. They found that the feed rate is the dominant factor affecting the surface roughness. Furthermore, Taguchi approach is one of popular optimization method for machining process. The related works can be found in [4]–[6].

Besides classical approach, modern optimization approach also frequently applied by researchers in optimizing the turning process. [7] for example had study the possible minimum cost that can be achieved for their turning process using Genetic Algorithm (GA). The optimization results indicated that the GA able to achieve minimum production cost, while considering technological and material constraint. However, the standard GA approach had a problem with premature convergence, where the output result mostly is the local optimum. Therefore, a number of run is required before the final conclusion can be made.

Particle Swarm Optimization (PSO) approach also had been implemented to optimize turning parameter [8]. In this work, two important response parameters have been measured; surface roughness and tool life. The result indicated that the PSO able to converge to global optimum. However, in this work they did not compare the PSO performance with any other algorithm. Meanwhile [9] compared performance of GA, Simulated Annealing (SA) and Ant Colony Optimization (ACO) in optimizing multi-pass turning process. They found that ACO came out with better solution compare with GA and SA.

This paper presents the study to minimize production cost for CNC roughing turning process using Ant Colony Optimization (ACO) algorithm. The ACO is selected because of its performance in multi-pass milling as suggested by [9]. The rest of the paper is organized as follow; Modelling of Turning Process, Ant Colony Optimization and Optimization Result and Conclusions.

Modelling of Turning Process

The purpose of this study is to minimize roughing turning cost while maintaining the power consumption and also surface roughness below the maximum allowable value. According to [10], the production cost per unit, C_u for turning process can be represented as follows:

$$C_u = C_o.t_m + (t_m/T) \times (C_o.t_{cs} + C_t) + C_o (t_h + t_r) + C_m \quad (1)$$

C_u = Production cost/unit (USD)
C_o = Operating cost (USD 0.35/min)
C_m = Material cost/unit (USD 2.33/unit)
t_m = Machining time (min)
T = Taylor's tool life (min)
T_{cs} = Tool change time (0.5 min/edge)
C_t = Tool cost per cutting edge (USD 1.75/edge)
t_h = Loading and unloading time (0.13 min/pass)
t_r = Quick return time (0.13 min/pass)

Meanwhile, the cutting time per pass is;

$$t_m = D.L / 1000.V.f \quad (2)$$

D = Diameter of the work piece (152 mm)
L = Length of the work piece (203 mm)
V = Cutting speed (V_{min} = 30 m/min ; V_{max} = 200 m/min)
f = Feed rates (f_{min} = 0.254 mm/rev ; f_{max} = 0.762 mm/rev)

The Taylor's tool life is presented as follow;

$$V. f^{a1}. doc^{a2}. T^{a3} = K \quad (3)$$

doc = depth of cut (doc_{min} = 2.0 mm ; doc_{max} = 5.0 mm)
a_1, a_2, a_3 and K are constants with the following values;
a_1 =0.29,
a_2 = 0.35,
a_3 = 0.25 and
K=193.3

In this problem, some constraints were set to ensure that the generated parameters will not harm the quality characteristic. The power limitation is given as below:

$$0.0373V^{0.91}.f^{0.78}.doc^{0.75} \leq P_{max} \quad (4)$$

Where P_{max} = 5 kW as stated in machine manual. Besides that, the maximum allowable surface roughness Ra_{max} = 12 µm, which represent by the following equation.

$$0.014785\ V^{1.52}.f^{\ 1.004}.doc^{0.25} \leq Ra_{max} \quad (5)$$

Ant Colony Optimization Algorithm

ACO is a multi-agent system that iteratively searches for optimal solutions. The ACO algorithm has been applied to different type of engineering problems. The ACO algorithm can be applied to another problem by following the algorithm in its procedure. The procedure give the algorithm step how to apply the optimization process using Ant Colony Optimization.

The general procedure of ACO as explained by [11] is given as follow:

Procedure: ACO
1: Create construction graph
2: Initialize pheromone values
3: while not stop-condition do
4: Create all ants solutions
5: Perform local search
6: Update pheromone values
7: end while

The construction graph is created in a way such that the ants can use this graph to walk from node to node over the edges to find a solution to the given problem. Usually this graph is fully connected to prevent deadlock situations in which an ant is stuck on a certain node without possible edges to move on. Several combinatorial optimization problems can be translated into an equivalent graph structure.

Probability to choose a path is given below. N_i^k is the set of nodes that ant k still has to visit when it is on city *i*. $\eta_{ij} = 1/d_{ij}$ is the inverse magnitude between cities *i* and *j* (heuristic value known a priori of the algorithm execution). τ_{ij} is the amount of pheromone dropped on the link between *i* and *j* at a particular time. α and β are two parameters determining the relative influence of τ and η.

$$p_{ij}^k = \frac{[\tau_{ij}]^\alpha[\eta_{ij}]^\beta}{\sum_{l\in N_i^k}[\tau_{ij}]^\alpha[\eta_{ij}]^\beta} \quad (6)$$

To update the pheromone, the following formula is applied, where ρ is the evaporation rate ($0 \leq \rho \leq 1$), *m* the number of ants.

$$\tau_{ij} = (1-\rho)\cdot\tau_{ij} + \sum_{k=1}^{m}\Delta\tau_{ij}^k \quad (7)$$

Optimization Result and Conclusions

The turning process optimization has been done using the ACO algorithm. For comparison purpose, four optimization results using different algorithms that were adopted from [10;12] are included in this paper.

Based on the result in Table 1, the fittest point with the most minimum total cost per unit are the output from Two-point Crossover GA (TP-GA) and ACO with USD 2.64 per unit. However, ACO converge faster than TP-GA to reach optimum solution as shown by T_{opt}. TP-GA required 47.2 seconds to obtain optimum solution, while ACO only need 21.5 seconds to reach similar solution.

This paper implemented the ACO algorithm in order to optimize turning process for roughing cut. The result from ACO algorithm indicated that this algorithm able to search for optimum solution faster than comparison algorithm. In this case the convergence time has reduced for 54%. In future, we plan to optimize the turning process for both roughing and finishing cut.

Table 1: Optimization result of turning process

Optimization Algorithm	T_{opt} (sec)	V (m/min)	f (mm/rev)	doc (mm)	P (kW)	Ra (µm)	C_u (USD)
Nelder-Mead Simplex	N/A	118.32	0.75	2.2	4.14	9.3	2.75
Boundary Search Procedure	N/A	114.02	0.68	3	4.68	9.72	2.84
Genetic Algorithm	33.4	114.49	0.67	2	3.41	9.59	2.72
Two-point Crossover GA	47.2	81.42	0.76	2	2.78	10.72	2.64
Ant Colony Optimization	21.5	80.64	0.762	2	2.76	10.58	2.64

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