Optimization of Turning Parameters to Minimize Production Cost using Genetic Algorithm

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Abstract — **In material removal process, turning is one of the oldest processes that were introduced to remove unwanted material by rotating the workpiece. The turning process 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. 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. 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 genetic algorithm (GA) method with some modification. The result shows that, the GA with modification was capable to reduce 2.9% of production cost compare to existing GA and two other methods. Therefore the optimum parameter setting which produce minimum production cost and in acceptable quality range was established.**

Keywords - Turning optimization, machining optimization, genetic algorithm

I. 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 [2].

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 [3].

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 using genetic algorithm (GA) method.

II. PREVIOUS LITERATURE

In previous research, M.Nalbant, H.Go'kaya and G.Sur (2006) use the Taguchi method is used to find the optimal cutting parameters for surface roughness in turning. The experimental results demonstrate that the insert radius and feed rate are the main parameters among the three controllable factors (insert radius, feed rate and depth of cut) that influence the surface roughness [4].

In 2000, Q.Meng et.al justify a method is described for calculating the optimum cutting conditions in turning for minimize cost. As a result, in determining the optimum cutting conditions for economic criteria, the most important parameters are cutting speed, feed rate and depth of cut [5]. J.Wang et.al (2001) uses the deterministic optimization approach involving mathematical analyses in their studies. It concludes that the substantial benefits in production time and cost per component that can be achieved when using the optimized cutting conditions rather than handbook recommendations [6].

The most relevant study was done by Saravanan (2006) which introduce genetic algorithm technique to optimize CNC turning parameter [7]. The result then was compared with other technique such as Nelder-Mead Simplex and Boundary search procedure. This study will concentrate to improve the genetic algorithm that used by Saravanan (2006), so that it will come out with better solution. Therefore all the related data and equation from his work will be directly used without any modification.

In this study, steel rod (0.2% of carbon) with diameter 152 mm and length 203 mm is considered. Three input parameter that will be consider are cutting speed, feed rate and depth of cut. These parameters were chosen based on few selected previous research and journals in the same field of area. The parameter range is presented as follows;

TABLE 1 PARAMETER RANGE

Parameter	Range
Cutting Speed ,V	**30 -200 m/min**
Feed Rate , f	**0.254 – 0.762 mm/rev**
Depth of Cut , doc	**2.0 – 5.0 mm**

III. GENETIC ALGORITHM

Genetic algorithm (GA) is a programming technique that mimics biological evolution as a problem-solving strategy. The input of the GA is a set of potential solutions to that problem, the aim of the GA being to improve them with generated initialize randomly [8].

The purpose of using GA in this study is to determine the optimum value for cutting speed, feed rate and depth of cut, so that the ultimate goal to minimize the unit production cost will be achieved. In GA, there are five standard steps to be follows which consist of initialization, evaluation, selection, reproduction and termination.

A. Initialization

The purpose of this step is to generate initial chromosome of solution. Since the population is set to 100, thus 100 chromosomes for initial solutions within the limit range were generated.

B. Evaluation

Each of chromosomes from initial population is being evaluated in this step. For this purpose, the objective function for this problem needs to be established. According to Saravanan (2006), the production cost per unit, C_u for turning process can be represented as follows [7]:

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

Where;

C_u = Production cost/unit (USD)
C_o = Operating cost, (USD 0.35/min)
C_m = Material cost/unit (USD 1.85/unit)
t_m = Machining time (min)
T = 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)
tr = 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)

Saravanan (2006) also presents the Taylor's tool life as follow [7];

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

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:

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

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

$$0.014785 \times {}^{V1.52} f^{1.004} doc^{0.25} \leq R_{a\ max} \quad (5)$$

C. Selection

The purpose of the selection is to emphasize the fitter individuals in the population. It's also must be balanced with variation of crossover and mutation. When strong selection means that suboptimal, highly fit individual will take over the population, meanwhile too weak selection will result in too slow evolution. Roulette wheel selection is used to select chromosomes to be reproduced in the next step.

D. Reproduction

In 'Reproduction', a new set of chromosome will be produced by using 'Crossover' and 'Mutation' method. The selected parents from previous step will undergo the Crossover which use 'Two Point Crossover' technique. In previous work which suggested by Saravanan (2007), the 'single point crossover' was applied [7].

In this study 'two point crossover' is applied because the changes in chromosome become more efficient. To illustrate the differences between 'single point crossover' and 'two point crossover', let consider a set of parent chromosome as follow.

(P1) = 100001000010000

(P2) = 110101101011010

TABLE 2 EXAMPLE OF SINGLE POINT CROSSOVER

Step	Single point crossover	Example
1	Generate a random number between 1 to *n-1* (number of allele)	In this case, n=15. Let random number, *r* = 10
2	Cut the chromosome at the r^{th} allele	P1 = 1000010000 | **10000** P2 = 1101011010 | **11010**
3	Change the position of the remaining allele	P1 = 1000010000 | ↓ **10000** ↑ P2 = 1101011010 | **11010**
4	New chromosome produced	C1= 1000010000**11010** C2= 1101011010**10000**

TABLE 3 EXAMPLE OF TWO POINT CROSSOVER

Step	Two point crossover	Example
1	Generate two different random number between 1 to *n-1*	In this case, n=15. Let random number, *r1*=7 & *r2*=13
2	Cut the chromosome at the r^{th} allele	P1 = **1000010** | 000100 | **00** P2 = **1101011** | 010110 | **10**
3	Change the position of the allele in first and third division	P1 = **1000010** | 000100 | **00** P2 = **1101011** | 010110 | **10**
4	New chromosome produced	C1= **1101011**000100**10** C2= **1000010**010110**00**

After that 'Uniform Mutation' taken place to avoid trapping in local optimum. For this problem, probability of crossover, P_c and probability of mutation, P_m were set to 0.6 and 0.2 respectively.

E. Termination

Termination step is to stop the simulation, when certain criterion was met. In this study, the termination was set when the number of generation achieve 10,000 generations.

IV. Result And Discussion

In previous research that was done by Saravanan (2006), he was compared the results that acquired using GA with two other methods; Nelder-Mead Simplex (NMS) and Boundary Search Procedure (BSP) [7]. The optimum result that were obtained by Saravanan (2006) is presented in Table 4 below

TABLE 4 OPTIMUM RESULTS FROM PREVIOUS RESERCH [7]

Method	doc (*mm*)	V (*m/min*)	f (*mm/rev*)	P (*kW*)	Ra (*µm*)	Cu (*USD*)
NMS	2.2	118.32	0.75	4.14	9.3	2.75
BSP	3.0	114.02	0.68	4.68	9.72	2.84
GA	2.0	114.49	0.67	3.41	9.59	2.72

In this study, some modification was made in 'Reproduction' step by introducing 'two point crossover' instead of 'single point crossover' as presented by Saravanan (2006). From the numerical experiment, five fittest points were selected and shown in Table 5.

TABLE 5 OPTIMUM RESULT USING GA WITH TWO POINT CROSSOVER

No	doc (*mm*)	V (*m/min*)	f (*mm/rev*)	P (*kW*)	Ra (*µm*)	Cu (*USD*)
1	2.0	81.34	0.76	2.77	10.69	2.65
2	2.0	81.42	0.76	2.78	10.72	2.64
3	2.2	78.71	0.73	2.83	10.04	2.67
4	2.1	78.67	0.75	2.70	10.03	2.66
5	2.0	84.61	0.75	2.85	11.21	2.66

According to Table 5, the fittest point with the most minimum total cost per unit is the second point which came out with USD 2.64 per unit. The total cost that produced using GA with 'two point crossover' is lower than previous technique that used in Saravanan (2006). However, the surface roughness, Ra predicted to be little bit higher compare to result that acquired by Saravanan (2006), but it still in the acceptable range (<12 µm).

V. Conclusion

This research modified the existing GA to minimize production cost per unit. The final result show that the modified GA was reduced the production cost per unit for 2.9% from USD 2.72 to USD 2.64. The modified GA produced better solution because ‘two point crossover’ varies and accelerate the convergence of chromosome compare to ‘single point crossover’. Besides that, ‘two point crossover’ also has advantage to produce diverge chromosome because the parent chromosome being divided into three divisions.

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