An Experimental Study of the Application of Gravitational Search Algorithm in Solving Route Optimization Problem for Holes Drilling Process

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Abstract**—**Previously, route planning in holes drilling process has been taken for granted due to its automated process, in nature. But as the interest to make Computer Numerical Control machines more efficient, there have been a steady increase in number of studies for the past decade. Many researchers proposed algorithms that belong into Computational Intelligence, due to their simplicity and ability to obtain optimal result. In this study, an optimization algorithm based on Gravitational Search Algorithm is proposed for solving route optimization in holes drilling process. The proposed approach involves modeling and simulation of Gravitational Search Algorithm. The performance of the algorithm is benchmark with one case study that had been frequently used by previous researchers. The result indicates that the proposed approach performs better than most of the literatures.

Keywords**—** route optimization problem, printed circuit board, gravitational search algorithm, computational intelligence.

I. INTRODUCTION

OPTIMAL route planning is necessary for reducing the time for the Computer Numerical Control (CNC) machine to complete its task. The least time taken for a CNC machine to complete its task, the greater the yield it obtained. Does reduces the cost of producing an item. Currently, route planning in CNC machine is done using Nearest-Neighbor Algorithm (NNA). The algorithm might be simple to implement but do not promise optimal solution. For that reason, many researchers and academicians attempt to solve the problem by proposing numerous algorithms.

Kolahan and Liang [1] in 1996 proposed the implementation of Tabu Search (TS) algorithm. Few year later, the authors proposed an improved version of the TS algorithm in [2]. Kentli and Alkaya [3] proposed a novel hybrid algorithm, Record-To-Record Travel with Local Exchange Moves (RRTLEM) in finding the optimized sequence. In year 2004, Onwubolu and Clerc [4] proposed the implementation of Particle Swarm Optimization (PSO). While, in year 1995, Sigl and Mayer [5] proposed the use of 2-Opt Heuristic Evolutionary (HE) algorithm in tackling the route optimization in holes drilling process. Implementation of Genetic Algorithm (GA) is done by Quedri et al. [6] in order to find the feasibility of GA in solving actual solving holes cutting process. While Ghaiebi and Solimanpur [7] had introduced an Ant Algorithm (AA) for holes drilling of multiple holes sizes. In year 2010, Z. Tahir et al. [8] proposed the use of Euclidean Travelling Salesman Problem (ETSP) on actual CNC machine.

In year 2006, Zhu highlighted in [9] that PSO might convergences prematurely. The author then proposed an improved algorithm of PSO which involved with Order Exchange List (OEL) and Order Exchange Unit (OEU). The author proved that these components able to improve the result of conventional PSO, especially in the area of premature convergence. The author use a case study of a Printed Circuit Board (PCB) consists of 14 holes of same size. The author then extend his work with different case studies in [10].

Interestingly, the case study in [9] has been taken by other papers for benchmarking purpose. Adam et. al. [11] proposed a diferent PSO model to solve the case study. A year later, Othman et al. [12] applied Binary PSO (BPSO) on the same case study. Result indicates slight improvement compared to [10] but the author also notice that BPSO convergence prematurely and trapped in two local minima. In the same year, Saealal et al. [13] suggested the use of Ant Colony System (ACS) to solve the case study. Ant Colony System performs really well for the case study due to the nature of route optimization problem which is fundamentally based from Traveling Salesman Problem (TSP).

M. M. Ismail et al. proposed the implementation of two latest Computational Intelligence algorithms: Firefly Algorithm (FA) in [14] and Magnetic Optmization Algorithm (MOA) in [15]. Both finding indicates slight improvement from [12] but not able to achieve result as [13]. Using the same case study in [9], this paper attempt to analyse the performance of Gravitational Search Algorithm (GSA) compared to other mentioned algorithms: [9,11-14]..

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II. Problem Formulation

As stated earlier, routing problem is a subset of TSP and many literatures had covered TSP formulation in great details [11-14]. This paper adapts the explanation given in [11-14] with purpose to give basic idea to the reader regarding the distance formulation in TSP. Normally, the machine will travel around the PCB to drill all the holes setting by the NCB files starting from its initial position (0,0), and it will return back to initial position again once the task is complete. The initial position will set as hole 0 in this project paper. Basically, the distance of the path is fundamentally can be calculated using TSP which formula written as in Eq. 1 [11-14].

$$C_{total} = \sum_{i=0}^{n} \sum_{j=0}^{n} \left(|x_i - x_j| + |y_i - y_j| \right) \times p_{ij} \quad (1)$$

where n is the number of holes needed. p_{ij} is the decision variable related to the assignment of the drill bit from hole i to j. If movement of the drill bit from hole i to j, thus, $p_{ij} = 1$, otherwise, $p_{ij} = 0$. Coordinates of hole i and j is (x_i, y_i) and (x_j, y_j). Since that most of PCB route problem is symmetrical TSP problem, thus, $C_{ij} = C_{ji}$.

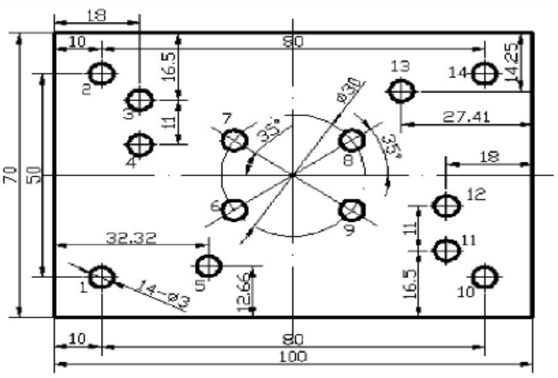

Fig. 1 PCB image of the 14 holes case study

The case study shown in Fig. 1 consists of 14 holes of same sizes PCB. This case study, distance between start position to first hole and last hole to start position was ignored and this lead to equation written stated in Eq. 2.

$$\min(C_{total}) = min\left(\sum_{i=1}^{n} \sum_{j=1}^{n} \left(|x_i - x_j| + |y_i - y_j| \right) \times p_{ij} \right) \quad (2)$$

As stated in [11-14], this case study produced 2 optimal solutions, it is either sequence:2 3-4-7-8-13-14-10-11-12-9-6-5-1 or inversed, 1-5-6-9-12-11-10-14-13-8-7-4-3-2. The optimal solution is 280mm

III. Modeling Route Optimization In Holes Drilling Process Using Gravitational Search Algorithm

Gravitational Search Algorithm was introduced by E. Rashedi et al. [16]. As the name suggested, the algorithm was inspired by the gravitational force between the planets. The authors had described in a great length in [16] on the implementation of the algorithm, thus, in this paper, we only going to touch the modelling part of the algorithm. In order to adapt original GSA into routing optimization problem, we proposed that the each agent to be model as Eq. 3.

$$\boldsymbol{X} = [vote\ for\ 1st\ hole\ location, vote\ for\ 2nd\ hole\ location, \ldots, vote\ for\ N-1\ hole\ location,\ vote\ for\ N\ hole\ location] \quad (3)$$

Hole location that has the largest number of vote will be the first city for the drill bit to visit, while the hole location with the least vote will be the last location for the drill bit to visit before going back to the initial position (home). For example, $\boldsymbol{X} = [29.45, 124.81, 98.10]$ means that the agent will travel Hole #2, first. Then follows by Hole #3 and Hole #1, respectively. In [11], the authors proposed the model as Eq. 4.

$$\boldsymbol{X} = [hole\ location\ for\ 1st\ sequence, hole\ location\ for\ 2nd\ sequence, \ldots, hole\ location\ for\ N-1\ sequence, hole\ location\ for\ N\ sequence] \quad (4)$$

A lot of intervention required to ensure that the agent does not violate routing optimization problem's constraints after the agent's position being updated for next iteration. That also the reason why the best found solution usually trapped at local minima of 298.02, 44 out 50 times. Not like in [11], this model can minimize the need of intervention for case like out of boundary condition. There might be possibility of more than one of the dimensions of the agent's position have the same numerical value of vote, although it is rarely occurred. If that happened, then the agent's position is randomize again. Algorithm of GSA can be obtained from [16] while the parameters chosen by us for the implementation on route optimization problem for holes drilling process as stated on the next section.

IV. Implementation And Experimental Result

The presented GSA approach was coded in MATLAB R2011a and the simulation was done on a laptop with a processor of 2.1 GHz Intel core i7 and 8GB RAM. As stated, in order to test the approach, Zhu's 14 holes drilling problem [9] has been chosen due to its popularity.

First of all, the proposed approach was tested in different parameters of β and ε for 5 computations per set of parameters. The parameter chosen for β= 0.1, 0.3 0.5, 0.7 and 0.9, while ε = 1, 5, 10, 15, 20. Table 1 shows the result obtained for average fitness and average global best iteration for 5 computations of the proposed approach. The reason of this test is to get the best parameters of GSA for further testing. From Table 1, it shows that the parameters: β = 0.3 and ε = 15 produced the best result in term of the average fitness and average iteration number.

From Table I, the best result collected was β = 0.3 and ε = 15, now, this parameters was used for another 50 computations. This to ensure the result obtained can be benchmark with previous literatures. Table II listed out the parameters for other literatures and this study. From the simulation, the proposed approach performs very well in term of speed where the average iteration number while the global convergence is faster than PSO and FA algorithm as in Table III. Like all other computational intelligence algorithms compared in Table III, the proposed approach able to obtain the best solution of 280 mm. The proposed approach managed to find the optimal solution for the problem, 20 out of 50 computations. The average of the computation is 289.5 mm. Both best solution of the case study can be obtained. There are several outliers obtained from the simulation. There is one time where the global best solution obtained is around 360mm. GSA has a better average fitness compared to GCPSO, PSO and BPSO. In addition, GSA managed to find the optimal route with smaller average iteration number. FA performs a bit better than GSA but computationally expensive.

TABLE I
RESULTS OBTAINED FOR DIFFERENT COMBINATION OF B AND ε

		β = 0.1	β = 0.3	β = 0.5	β = 0.7	β = 0.9
ε = 1	Average fitness	333.624	328.44	327.84	332.024	335.34
	Average global best iteration	913.4	1320.4	1174	1385	1116.2
ε = 5	Average fitness	321.824	316.512	316.512	310.916	320.016
	Average global best iteration	1659.2	1498	1498	1153.8	1546.4
ε = 10	Average fitness	302.308	300.464	300.464	302.484	302.308
	Average global best iteration	941.6	1024.2	1024.2	1157.4	941.6
ε = 15	Average fitness	302.416	282.824	301.084	309.036	308.392
	Average global best iteration	966.4	629.8	882.4	394.4	654.4
ε = 20	Average fitness	384.076	372.232	357.352	371.38	378.692
	Average global best iteration	390.4	1050.8	265	913	706.4

TABLE II
COMPARISON OF THE COMMON PARAMETERS USED IN SEVERAL LITERATURES WITH THIS STUDY

	Zhu	Adam et al	Othman et al	Ismail et al	This paper
Common Parameters					
Number of partiles, q	100	50	50	50	50
Number of iterations, t	10000	5000	2500	10000	2500
Number of simulations, s	50	50	50	50	50

TABLE III
COMPARISON OF THE RESULT OBTAINED IN SEVERAL LITERATURES WITH THIS STUDY

	Zhu	Adam et al.	Othman et al.	Ismail et al.	This paper
	GCPSO	PSO	BPSO	FA	GSA
Inertia weight, ω	0	0.9→0.4		-	-
The least iteration number while global convergence	70	118	71	22	87
The average iteration number while global convergence	1784	1415	783	1652.4	632.36
Length of optimization solution	280	280	280	280	280
Average fitness after computing 50 computations	289.6	292.3	296.0	288.2	289.5

V. CONCLUSION

In this study, the proposed approach that is GSA is implementing to find the optimized path for PCB holes drilling process. It is a simple method and easy to implement to find the best route for holes drilling process. The result collected by this paper clearly shows that the proposed approach performs better than several literatures. Further study is required in understanding the convergence property of GSA, especially in TSP.

REFERENCES

[1] Kolahan, F. and Liang, M (1996) Tabu search approach to optimization of drilling operations, Computers and Industrial Engineering, Vol. 1-2, No. 31, pp. 371-374.
[2] Kolahan, F. and Liang, M. (2000) Optimization of hole-making operations: a tabu search approach, International Journal of Machine Tools and Manufacture, Vol. 2, No. 40, pp. 1735-1753.
[3] Kentli, A. and Alkaya, A. F. (2009) Deterministic Approach to Path Optimization Problem, Ozean Journal of Applied Sciences, Vol.2, No. (2), ISSN 1943-2429.
[4] Onwubolu, G. C. and Clerc, M. (2004) Optimal path for automated drilling operations by a new Heuristic approach using particle swarm optimization, International Journal of Production research, Vol. 3, no. 42, pp. 473-491.
[5] Sigl, S. and Mayer, H. A. (2005) Hybrid Evolutionary Approaches to CNC Drill Route Optimization, Proceedings of Computational Intelligence for Modeling, Control and Automation, pp. 905-910.
[6] Qudeiri J.A. et al. (2007) Optimization of operation sequence in CNC machine tools using genetic algorithm, Journal of Advanced Mechanical Design, Systems, and Manufacturing, Vol. 1, No. 2, pp. 272-282.
[7] Ghaiebi, H. and Solimanpur, M. (2007) An ant algorithm for optimization of hole-making operations, Computers & Industrial Engineering, Vol. 52, No. 2, pp. 308-319.
[8] Tahir, Z. et al. (2010) CNC PCB drilling machine using Novel Natural Approach to Euclidean TSP, 3rd IEEE International Conference on Computer Science and Information Technology (ICCSIT), Vol. 5, pp. 481-485.
[9] Zhu G,-Y (2006) Drilling Path Optimization Based on Swarm Intelligent Algorithm, Proceedings of IEEE International Conference on Robotics and Biomimetics, pp. 193-196.
[10] Zhu, G.-Y. and Zhang, W. B (2008) Drilling path optimization by the particle swarm optimization algorithm with global convergence characteristics, International Journal of Production Research, Vol. 46, No. 8, pp. 2299-2311.
[11] Adam, A. et al. (2010) A Particle Swarm Optimization Approach to Robotic Drill Route Optimization, Fourth Asia International

Conference on Mathematical/Analytical Modelling and Computer Simulation, pp. 60-64.
[12] Othman, M. H. et al. (2011) A Binary Particle Swarm Optimization Approach for Routing in PCB Holes Drilling Process, International Conference on Robotic Automation System, pp. 202-206
[13] Saealal, M. S. et.al (2012) An Ant Colony System for routing in PCB drilling process, International Journal of Innovative Management, Information & Production. Volume 3, No. 1, pp. 50-56.
[14] Ismail, M. M. et al. (2012) Firefly Algorithm for Path Optimization, International Conference in Green and Ubiquitous Technology.
[15] Ismail, M. M. et. al. (2013) Route Planning in Holes Drilling Process Using Magnetic Optimization Algorithm for Electronic Manufacturing Sector, World Applied Sciences Journal, vol. 21, pp. 91-97.
[16] Rashedi, E. et al. (2009) GSA: A Gravitational Search Algorithm, Information Science, Vol. 179, No. 13, pp. 2232-2248.