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Route Planning Analysis in Holes Drilling Process Using Magnetic Optimization Algorithm for Electronic Manufacturing Sector

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Abstract: Electronic manufacturing sector uses computer numerical controlled machines for drilling holes. Most of the computer numerical controlled machines used nearest neighbour algorithm to plan the route for the drill bit to travel. Based on this motivation, this paper proposes an approach which is based on the experimentation of Magnetic Optimization Algorithm. In this implementation, each magnetic agent or particle in Magnetic Optimization Algorithm represents a candidate solution of the problem. The magnitude of the magnetic force between these particles is inversely proportional to the distance calculated by the solution they represented. Particles with greater magnetic force will attract other particles with relatively smaller magnetic force, towards it. The process is repeated until the stopping condition meets and the solution with lowest distance is taken as the best-found solution. Result obtained from the case study shows that the proposed

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approach managed to find the optimal solution. With this method, electronics manufacturing sector can optimize the drilling process hence will increase the productivity of the manufacturer. This study can be extended further by tuning the parameters of MOA in order to enhance the drilling route process.

Key words: Magnetic Optimization Algorithm % Swarm Intelligence % Route Planning % Holes drilling process % Computational Intelligence

INTRODUCTION

Computer Numerical Controlled (CNC) machines have advanced the holes drilling process as this manufacturing process now has been completely automated. Currently, most of the CNC systems, the end-to-end component design is computerized using Computer Aided Design (CAD) program. The program will produce a computer file called Numerical Controlled Drill (NCD) that can be interpreted by CNC machines. This file listed the sequence, location and sizes of each hole to be drilled. However, the NCD file only use Nearest Neighbour (NN) algorithm where the route planning obtained from this algorithm does not guaranteed optimal route.

The (Printed Circuit Board) PCB holes drilling route optimization problem is a subdivision of the Travel Salesman Problem (TSP). The TSP problem is a combinatorial problem where the objective is to find the sequence of cities to be visited for the salesman to complete his tour of *n* cities provided the inter-city distance. Similar to TSP, the optimized route in holes drilling process can be obtained by finding the holes sequences that requires minimal distance travelled by the drill bit. By obtaining the optimized route, the CNC machine is able to reduce its operational time per item, which leads to an increase in its yield as more tasks can be completed at a given time. The importance of improving of the CNC process is significant; this can be seen by numerous studies published.

Based on the reviewed literature [1-12], the earliest studies in holes drill routing was conducted by Kolahan and Liang [1] in 1996. The researchers suggested the use of Tabu search algorithm in solving case study, which consist of variable holes sizes. In addition, they have proposed an improved version of Tabu search algorithm [2]. Onwubolu and Clerc [3] proposed a Particle Swarm Optimization (PSO) algorithm for holes drilling problem. Another new algorithm called Record-to-Record Travel with Local Exchange Moves (RRTLEM) in finding the optimized sequence is proposed [4].

Focusing into CNC machine, the earliest work in holes drill routing problem was done by Sigl and Mayer [5] in 2005. They introduced the 2-Opt Heuristic Evolutionary (HE) algorithm in solving drill routing for Computer Numerical Control (CNC) machine. Quedri *et al*. [6] have implemented Genetic Algorithm (GA) to search the optimized route for holes cutting process in CNC machine tool. Similarly, Ghaiebi and Solimanpur [7] have introduced an Ant Algorithm for holes drilling of multiple holes sizes.

In 2006, Zhu [8] has found that the standard PSO algorithm does not promise global convergence in holes drilling problem. The author proposed an improved PSO based on a model with components: Order Exchange List (OEL) and Order Exchange Unit (OEU). These components are able to solve the constraints encountered in modeling standard PSO for PCB holes drilling problems. The author then implemented the proposed algorithm ion a case study, which consists of a PCB with 14-holes. Later, the proposed approach has been applied to different set of problems [9].

Several authors benchmark their proposed approaches by using the same case study. In 2010, Adam *et al*. [10] proposed a different model of PSO to tackle the case study. In the following year, Othman *et al*. [11] suggested that Binary PSO (BPSO) has shown better performance than [10] using the same case study. In the same year, Saealal *et al*. [12] have implemented Ant Colony System (ACS) in the case study. The results show that ACS performed really well as compared to other Swarm Intelligence (SI) approaches.

The objective of this paper is to use the MOA to solve the routing PCB holes drilling process. This paper also explains the detailed problem of interest and the mathematical formulation of the problem is defined. Next, the modeling of MOA in holes drilling route problems is explained, followed by the discussion of the implementation and the experimental results obtained based on the proposed approach and findings will be summarized.

MATERIALS AND METHODS

Route Planning Methods: As stated in [10-13], the total distance of the route, c_{total}, which is fundamentally formulated based on the Traveling Salesman Problem (TSP), can be expressed in equation (1).

$$C_{total} = \sum_{i=0}^{n} \sum_{j=0}^{n} C_{ij} \times p_{ij} \tag{1}$$

where n is the number of holes required. p_{ij} is the decision variable related to the movement of the drill bit from hole i to hole j. If there is a movement of the drill bit from hole i to hole j, p_{ij} = 1, otherwise, p_{ij} = 0. c_{ij} is the distance between hole r and hole s, which can be calculated using equation (2).

$$c_{ij} = |x_i - x_j| + |y_i - y_j| \tag{2}$$

where the coordinate of hole i is (x_i, y_i) and the coordinate of hole j is (x_i, y_i) and $c_{ij} = c_{ji}$. Hence, Equation (1) can be re-written as equation (3).

$$C_{total} = \sum_{i=0}^{n} \sum_{j=0}^{n} \left(\left| x_i - x_j \right| + \left| y_i - y_j \right| \right) \times p_{ij} \tag{3}$$

The case study used in this paper, as shown in Figure 1, is similar to the previous work, which has been carried out by Zhu [8], where the objective is to find the shortest distance for the drill bit to travel in completing its task.

The case study is a PCB, which consists of 14 holes. In the case study, all the holes are having the same size. The initial position is located at the top left corner of the PCB image. The cost (or distance) from initial position to the first hole and the last hole to the initial position are ignored to standardize the distance calculation obtained with [10-12]. Thus, the objective function of the problem is shown in equation (4).

$$min(C_{total}) = min(\sum_{i=1}^{n} \sum_{j=1}^{n} (| x_i - x_j | + | y_i - y_j |) \times p_{ij}) \tag{4}$$

The optimal solution of the case study can be either the route having sequence 2–3–4–7–8–13–14–10–11–12–9–6–5–1 or 1–5–6–9–12–11–10–14–13–8–7–4–3–2. The distance of the optimal solution is 280mm. Figure 2 shows the route of the optimal route for the case study.

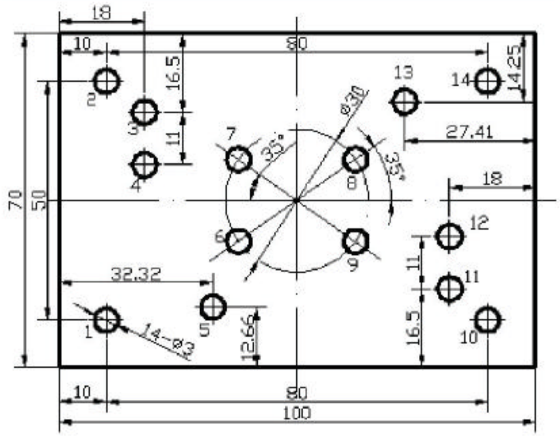

Fig. 1: A PCB image, which consists of 14 holes

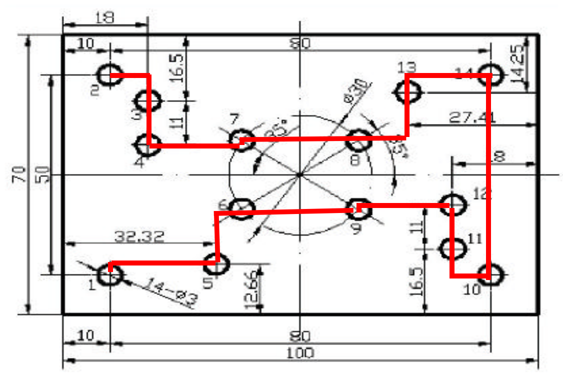

Fig. 2: The optimal route for the case study

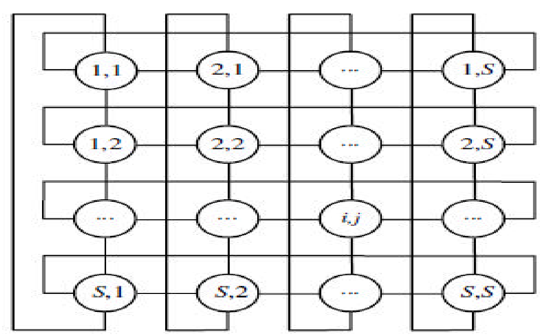

Fig 3: Structure of cellular lattice

Magnetic Algorithm Optimization: The magnetic force is one of four basic forces that occurred in our universe [14]. In magnetic field, a particle with higher mass will have a greater magnetic force that attracts other particles with smaller masses to move towards it. This simple concept is adapted to MOA where the mass of a particle at a given time is proportional to the fitness of the problem. In the cellular lattice model defines how magnetic particle could relate to each other [14]. Magnetic force of its neighborhood is shown in Figure 3. This model is

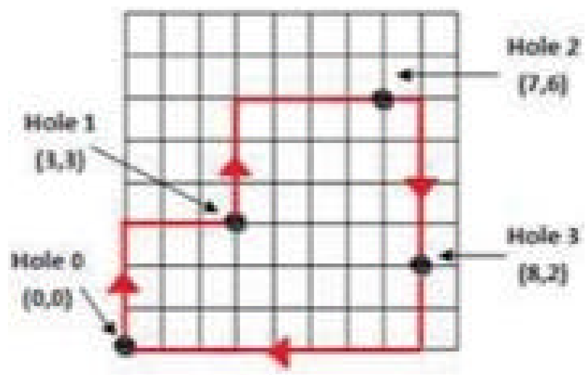

Fig. 4: Illustration of drill bit movement for $x_{31}^{z=7} = [12,-7,2]$

proposed to avoid prematurely convergence by the particles in MOA. Premature convergence leads to local optima solution.

The main gist of this paper is how TSP can be modeled using MOA. It is suggested that each particle in MOA represented a candidate solution of TSP. The particle's position and candidate solution of TSP can be generalized as in equation (5).

$$x_{ij,k}^{z,t} = [vote\ for\ 1st\ hole,...,vote\ for\ nth\ hole] \qquad (5)$$

where x^z is the z[th] particle position in search space. i and j indicate the coordinate of the particle in cellular lattice formation mentioned earlier. k is the dimension of the particle position. Maximum dimension of a particle position in the PCB holes drilling problem is equal to the number of holes that need to be drilled. The hole number with highest vote will be the first hole to be drilled by the drill bit while the hole number with the least vote will be the last hole to be drilled before the drill bit returned to the home location (#0). For instance, given that $x_{11}^{z=1}[1,10,3]$ and $x_{31}^{z=7}[12,-7,3]$. The first particle suggests a solution of 0 6 2 6 3 6 1 6 0 and the 7[th] particle suggests the solution of 0 6 1 6 3 6 2 6 0. The movement of the seventh particle is illustrated in Figure 4 [10-12].

Like any other nature-inspired optimization techniques, MOA consists of three main parts: initialization, fitness evaluation and improvement of agents. Algorithm 1 shows the pseudo code of MOA for TSP.

Algorithm 1: Pseudo code of MOA for routing in PCB holes drilling problem

```
Initialize PCB routing problem parameters: n and c_ij
Initialize MOA parameters: S, D, ", w and h
Randomly positioned the particle in search space with a
cellular lattice-like structure
while not termination condition do
t = t + 1
Find each particle's fitness using (4) and store it as magnetic field, b^z
if the particle fitness greater than global best do
Store solution offered by the particle and the distance value
end
Normalize b^z using (7)
Evaluate the particle's mass, m_ij^{z,t} using (8)
for all particles x_ij^{z,t} in do
Let f_ij^z = 0
Find n_ij^z
for all particles x_ij^{z,t} in N_ij do
update f_ij^z using (9)
end
for all particles x_ij^{x,t} in X^t do
update v_{ij,k}^{z,t+1} using (10)
update x_{ij,k}^{z,t+1} using (11)
perform correction if necessary
end
end
end
Display global best solution
```

The algorithm starts by initializing PCB routing problem and MOA parameters. The parameters and the suggested values are listed in Table 2 and Table 3. Then, all the particles are randomly assigned using the proposed model mentioned earlier. This can be mathematically written as equation (6).

$$x_{ij,k}^{z,t} = R(u_k, l_k) \text{ for } i,j = 1,...,S, k = 1,2,...,n \text{ and } t = 0 \qquad (6)$$

By taking the example earlier with an additional particle, these particles position after randomly assigned are $x_{11}^{1,0} = [1,10,3]$, $x_{31}^{7,0} = [12-7,2]$ and $x_{22}^{5,0} = [7,10,21]$. These steps are the first phase of any nature-inspired optimization techniques: the initialization phase.

In this paper, the proposed approach uses maximum iteration as the stopping condition. Then, we enter the second phase of any nature-inspired optimization techniques: the fitness evaluation. The fitness of the particles are calculated using equation (4) and stored as magnetic field, b^z. For example, fitness calculation of $x_{31}^{7,0} = [12-7,2]$ is 12 units. Not that the distance from home to the first hole and distance from last hole to home are not counted.

Then, the magnetic value using is normalized as in equation (7).

$$b_{ij}^{z} = \frac{b_{ij}^{z} - \min_{i,j=1\rightarrow S}(B_{ij}^{t})}{\max_{i,j=1\rightarrow S}(B_{ij}^{t}) - \min_{i,j=1\rightarrow S(B_{ij}^{t})}} \tag{7}$$

Next, the mass of the particles, m_{ij}^{z} is calculated using equation (8). The " and D are constant parameters of MOA. Following are the third phase of any nature-inspired optimization algorithm, the improvement of the agents or the learning phase.

$$m_{ij}^{z} = a + r \times b_{ij}^{z} \tag{8}$$

In the implementation, a = 1 and D = 1. Then, identify the lattice neighbours of the particles. Next, the magnetic force f_{ij}^{z} is calculated using equation (9).

$$f_{ij}^{z} = \frac{\left(x_{uv,k}^{z,t} - x_{ij,k}^{z,t}\right) \times b_{uv}^{z,t}}{\sqrt{\frac{1}{n} \times \sum_{k=1}^{n} \left(\frac{x_{uv,t}^{z,t} - x_{ij,k}^{z,t}}{uk - lk}\right)^2}} \tag{9}$$

Based on the force, the particle velocity and the particle position are updated using equations (10) and (11).

$$v_{ij,k}^{z,t+1} = \frac{f_{ij}^{z,t}}{m_{ij}^{z}} \times R(u_k, l_k) \tag{10}$$

$$x_{ij,k}^{z,t+1} = x_{ij,k}^{z,t} + v_{ij,k}^{z,t+1} \tag{11}$$

After updating the particle position, it is necessary to check for any redundancy in the value of the voting. For example, $x_{11}^{1,1} = [9,9,6]$ leads to an invalid solution. Here, it can be simply corrected by initializing that particle using equation (6). The process is repeated until maximum iteration is met. Then the global best solution is taken as the final solution.

RESULTS AND DISCUSSION

The proposed approach is written in MATLAB and the simulation is performed 50 times on a desktop equipped with 1.86GHz Intel Pentium Core 2 processor with 2GB RAM. Table 1 lists the information related to the case study shown in Figure 1. Table 2 lists the parameters values used throughout this study in solving the case study. Table 3 contains the comparison between the results obtained by other literatures and this study. Each computation takes an average duration of 1.5 hours to complete.

From Table 3, the proposed approach is able to find the optimal solution of the case study, which has a fitness of 280mm. This indicates that the proposed approach able to solve the problem given the common parameters values are the same as in equation [8]. In terms of average fitness, the proposed approach has a better fitness compared to GCPSO, PSO and BPSO but has a higher fitness value compared to ACS. It is not surprise that ACS performs well compared to the proposed approach as ACS was initially designed to solve TSP, which inter related to routing problem. Lower average fitness translates to a better choice of path selection by the CNC machine in completing its task.

Table 1: Information of PCB used in the case study

Number of holes, *n*	14	Length	100mm	Wide	70mm		
Hole Number	Coordinate (*x*, *y*)	Hole Number	Coordinate (*x*, *y*)	Hole Number	Coordinate (*x*, *y*)	Hole Number	Coordinate (*x*, *y*)
0	(0,0)	1	(10,60)	2	(10,10)	3	(18,16.5)
4	(18,27.5)	5	(32.32,57.34)	6	(37.7,43.6)	7	(37.7,26.4)
8	(62.3,26.4)	9	(62.3,43.6)	10	(90,60)	11	(82,53.5)
12	(82,42.5)	13	(72.59,14.25)	14	(90,10)		

Table 2: Parameters used by related literatures

	Zhu's [8]	Adam [10]	Othman [11]	Current study
Common Parameters				
Number of agents, q	100	50	50	50
Number of iterations, t	10000	5000	2500	10000
Number of computations	50	50	50	50
PSO Parameters				
Inertia weight, T	0.0, 0.5, 1.0	0.9 6 0.4	Not applicable	
Cognitive component, c_1	Not available	1.42	Not applicable	
Social component, c_2	Not available	1.42	Not applicable	
r_1 and r_2	Random number [0,1]	Not applicable		
MOA Parameters				
″	Not applicable	1		
D	Not applicable	1		

Table 3: Comparison of results obtained by related literature

	Zhu [8]			Adam [10]	Othman [11]	Saelel [12]	Current study
	GCPSO			PSO	BPSO	ACS	FA
Inertia weight, T	0	0.5	1.0	0.9 6 0.4		Not Applicable	Not Applicable
The least iteration number while global convergence	70	601	93	118	71	193	159
The average iteration number while global convergence	1784	3549	2104	1415	783	1037	2830
Length of optimal solution	280	280	280	280	280	280	280
Average fitness after computing 50 computations	305.7	307.3	289.6	292.3	296.0	283.6	287.8

CONCLUSION

This paper presents the application of MOA with voting modeling in PCB routing problem. The process of finding the shortest distance for the drill bit to drill all the holes using MOA has been achieved. Result obtained from the case study shows that the proposed approach managed to find the optimal solution. With this method, electronics manufacturing sector can optimize the drilling process hence will increase the productivity of the manufacturer. This study can be extended further by tuning the parameters of MOA in order to enhance the drilling route process.

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