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ANANT COLONY SYSTEMFOR ROUTING IN PCB HOLES DRILLING PROCESS

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Abstract. *Most electronic manufacturing industries use computer numerical controlled (CNC) machines for drilling holes on printed circuit board (PCB). Some machines do not choose the optimal route when completing their tasks. Hence, this paper proposes an approach, which is based on ant colony system (ACS), for finding the optimal route in PCB holes drilling process. In ACS, an artificial ant starts to move from a random hole location and moves to the next hole location, based on the pheromone level between the locations of two holes. The higher the pheromones level, the higher the chance for the artificial ant to choose that path. At the same time, that ant deposits its pheromone on the path chosen. This process is repeated until the artificial ant builds a solution, which is evaluated with other artificial ants' solutions. The best artificial ant deposits additional pheromone to its path. The best-found path is updated as the iteration continues. Experimental result indicates that the proposed ACS-based approach is capable to efficiently find the optimal route for PCB holes drilling process.*

Keywords: Ant Colony Optimization; Ant Colony System; Printed Circuit Board; Routing Problem

1. Introduction. One of the earliest studies in routing for PCB holes drilling process is conducted by Kolahan and Liang (1996). They proposed the use of Tabu search algorithm to solve a case study, which consist of variable holes sizes. Later, they (2000) have proposed an improved version of Tabu search algorithm. On the other hand, Onwubolu and Clerc (2004), have proposeda Particle Swarm Optimization (PSO) algorithm for holes drilling problem. Another significant finding is the research carried out by Kentli and Alkaya (2009), where Record-to-Record Travel with Local Exchange Moves (RRTLEM) algorithm has been proposed in finding the optimized sequence.

Specifically in CNC machine, one of the earliest routing problems in holes drilling is a paper written by Sigl and Mayer (2005). They introduced the 2-Opt Heuristic Evolutionary algorithm in solving drill routing for Computer Numerical Control (CNC) machine. Using CNC as the subject, Quedri*et al.* (2007) employed Genetic Algorithm (GA) in searching the optimized route for holes cutting process in CNC machine tool. Also, Ghaiebi and Solimanpur (2007) have introduced an Ant Algorithm (AA) for holes drilling of multiple holes sizes.

In 2006, Zhu (2006) has found that the standard PSO algorithm does not promise global convergence in holes drilling problem. Hence, an improved PSO has been proposed to solve the problem. The proposed model introduced Order Exchange List (OEL) and Order Exchange Unit (OEU) in order to solve constraints encountered in modeling standard PSO for PCB holes drilling problems. A case study, which consists of a PCB with 14holes taken from TSP Library of Heidelberg University, is chosen for experimental purpose. Later, Zhu and Zhang (2008) applied the proposed approach to different set of problems. Based on the same case study, this paper proposes the use of Ant Colony System (ACS) introduced by Marco Dorigo (2004) to solve a 14-holes case study of PCB holes drilling process. The ACS searches the route need to be taken to complete the path which having the minimum distance.

2. Routing Problem in PCB Holes Drilling. The total distance of the route, c_{total}, which is formulated based on the Traveling Salesman Problem (TSP), can be expressed as Eq. (1).

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

Where n is the number of holes required. p_{ij} is the decision variable related to the movement of the robotic arm from hole i to hole j. If there is a movement of the robotic arm from hole$i$ to hole$j$, $p_{ij} = 1$, otherwise, $p_{ij} = 0$. The coordinate of hole$i$ is (x_i, y_i) and the coordinate of hole j is (x_j, y_j).

The case study used in this paper, as shown in Fig. 1(a), is similar to the previous work, which has been carried out by Zhu (2006) where the objective is to find the shortest distance for the robotic arm to travel in completing its task. The case study is a PCB, which consists of 14 holes. It is assumed that 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.

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 is shown inFig.1(b).

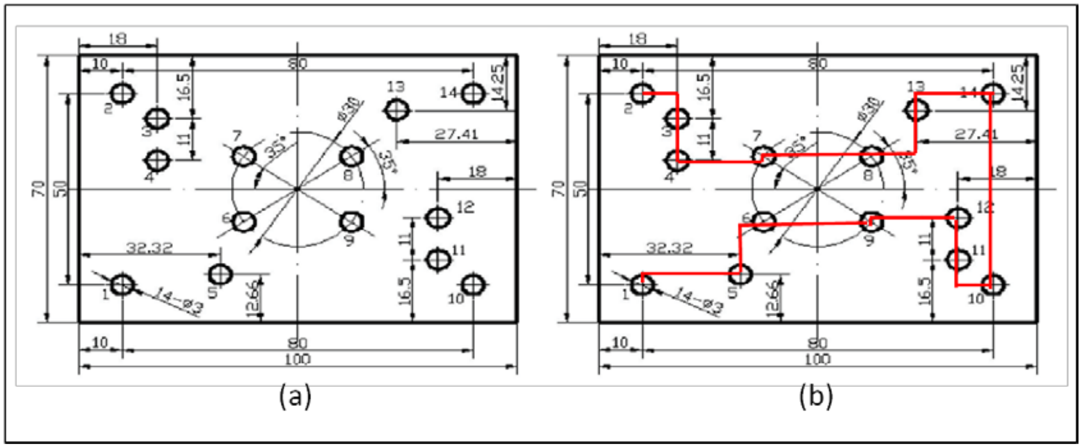

FIGURE 1. (a) PCB image (b) Route with optimal solution.

3. Modeling PCB Hole Drilling Route Problem in ACS. In holes drilling process, the movement of the robotic arm of a CNC machine begins at an initial position (Hole 0) and travels according to the predetermined sequence of holes. After completing its task, the robotic arm returns to the initial position.

In this study, each ant in ACS represents a feasible solution. A feasible solution in PCB holes drilling is simply a complete sequence such that all holes must be visited and each hole is visited once only. Algorithm 1 shows the ACS algorithm for PCB holes drilling problem. One of the components that need to be initialized is the pheromone level. The pheromone is be initialized to a constant value, τ_0, based on Eq.(2).

$$\tau_{ij\,(0)} = \tau_0 = \frac{1}{N \times c_{random}}\,,\; i \in N \text{ and } j \in N \quad (2)$$

Where N is the total number of holes that need to be visited, c_{random} is the distance (cost) of the sequence generated randomly, and i and j are the number from 0 to N,which represent the holes numbering. Other ACS parameters need to be initialized are as listed in Table 1.

TABLE 1. ACS parameters

Algorithm 1 Ant Colony System (ACS) Algorithm for PCB Holes Drilling Route Problems

```
Load PCB data, initialize ACS parameters (refer to Eq.(2) and Table 1)
loop
    loop
        Each ant is randomly positioned at its first hole
        loop
            Each ant applies the state transition rule (refer Eq.(3)) to incrementally
            build a feasible (same hole visited once and all holes visited) solution
            Apply the local pheromone update using Eq.(6)
        until all ants have built complete solutions
    until number of solutions in archive are equal with number of ants
    loop
        Calculate the ant's fitness using Eq.(1)
        if fitness function of the ant is better than the best found then
```

Store the ant's fitness function & solution as the new best found
end if
until all ants' solutions have been evaluated
Apply the global pheromone update using Eq.(7) on the route of the best-found ant
until fulfill stopping criteria

The location of the first hole is determined by ants randomly based on their firstly visited hole. Then, assume an ant is positioned at hole i. At a particular iteration,t, the next hole,j, is determined according to the state transition rule as shown in Eq. (3).

$$s = \begin{cases} \arg\max_{u \in \mathrm{N}_i^h(t)} \{\tau_{ij}(t)\eta_{ij}(t)\}, & r \le r_0 \\ S, & r > r_0 \end{cases} \quad (3)$$

Where $r \sim U(0,1)$ and $r_0 \in [0,1]$ are variables that control the ratio of exploration and exploitation. In this study, $r_0 = 0.5$.The state transition rule is influenced by the pheromone level,$\tau_{ij}(t)$, and the distance between holes,$\eta_{ij}(t)$, which is a variable that is related to the inter-hole distance as shown in Eq.(4).

$$\eta_{ij}(t) = \frac{1}{c_{ij}} \quad (4)$$

Where c_{ij} is the distance from hole i to hole j.Here, a taboo list is employed to remember the previously visited holes and to prevent an ant from choosing the previously visited hole.

In Eq. (6), $\mathrm{N}_\mathrm{i}^\mathrm{h}$ is a set of valid holes to visit and$S \in \mathrm{N}_i^\mathrm{p}$ is a hole randomly selected according to probability,$p_{ij}^h(t)$, in Eq.(5).

$$p_{ij}^h(t) = \frac{\tau_{ij}(t)\eta_{ij}(t)}{\sum_{u \in \mathrm{N}_\mathrm{i}^\mathrm{h}} \tau_{ij}(t)\eta_{ij}(t)} \quad (5)$$

Once the ant chooses the next destination, the pheromone level, τ, is updated by using Local Pheromone Update equation as shown in Eq.(6).

$$\tau_{ij}(t+1) = (1-\rho_1) \times \tau_{ij}(t) + \rho_1 \times \tau_0 \quad (6)$$

Where $\rho_1 \in [0,1]$, which is predefined by user, is the evaporate factor. After all ants have built their own solutions, their fitness are compared with others. The best-recordedantis chosen where the best ant's route will be awarded with extra pheromone based on Eq.(7). This part of ACS algorithm is called Global Pheromone Update.

$$\tau_{ij}(t+1) = (1-\rho_2) \times \tau_{ij}(t) + \rho_2 \times \Delta\tau_{ij} \quad (7)$$

Where ρ_2 are the evaporate factors, predefined by user and $\rho_2 \in [0,1]$. $\Delta\tau_{ij}$ value can be obtained using Eq.(8), where it is inversely proportional to the distance obtained by the best ant's route, $c_{BestAnt}$, for that iteration.

$$\Delta\tau_{ij} = \frac{1}{c_{BestAnt}} \quad (8)$$

The algorithm is repeated until maximum iteration reached. Lastly, the algorithm will return the best-found sequence with the lowest distance as the recommended sequence.

4. Implementation and Experimental Result. The program is written in Visual Basic 6 and the simulation is performed 50 times on a laptop that is equipped with 2GHz Intel Pentium Dual Core processor with 2GB RAM. Table 2 lists out the complete information of the PCB used in the experiment. The initial position is located at the top left corner of Figure.1(a).

The proposed ACS model has parameters as shown in Table 3. In the same table, Zhu's PSO (2006) parameters included. On the other hand, Table 4 shows the result of 50 computations of the proposed model with Zhu's literature result listed for comparison.

The result clearly stated the superiority of the proposed model compared to standard PSO and GCPSO in terms of length optimal solution, average iteration number, convergence and average fitness after 50 computations. On average, the proposed modelconvergences faster than the standard PSO and GCPSO with average of 1037 iterations. Figure 4 shows one of the convergence curve obtained from the experiment. The experiment result obtained the proposed model able to find the optimal solution with the success rate of 86%. This high success rate due to the heuristic component in ACS, η_{ij} which has information of the distances between the inter-holes.

TABLE 2. A complete PCB data

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 3. Comparison of the PSO parameters used by Zhu and this study

	Zhu's	Ours
Common Parameters		
Number of agents, i	100	25
Number of iterations, t	10000	2500
Number of computations	50	50
PSO Parameters		
Inertia weight, ω	0.0, 0.5, 1.0	Not applicable
Cognitive component, c_1	Not available	Not applicable
Social component, c_2	Not available	Not applicable
r_1 and r_2	Random number [0,1]	Not applicable
ACS Parameters		
Decision factor, r_0	Not applicable	0.5
Local evaporation factor, ρ_1	Not applicable	0.3
Global evaporation factor, ρ_2	Not applicable	0.3

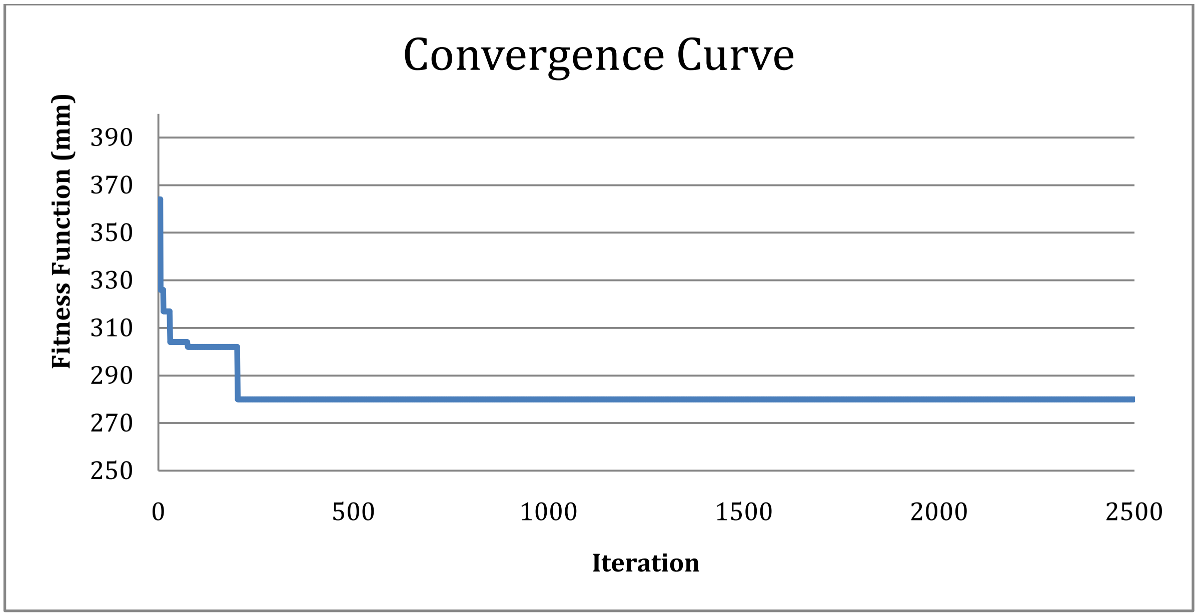

FIGURE 4. A sample of convergence curve with fitness function of 280mm

TABLE 4. Comparison PSO resulted obtained by Zhu and this study

	Zhu's						Ours
	Global Convergence PSO			Standard PSO			ACS
ω	0	0.5	1.0	0	0.5	1.0	NA
The least iteration number while global convergence	70	601	93	-	-	118	193
The average iteration number while global convergence	1784	3549	2104	-	-	1415	1037
Length of optimal solution (mm)	280	280	280	-	-	280	280
Average fitness after computing 50 computations (mm)	305.7	307.3	289.6	-	-	300.7	283.6

5. Conclusion. Ant Colony System was implemented for PCB holes drilling route optimization problem with objective to minimize the distance of the route chosen by the CNC machine. The result clearly proves that ACS able to find the optimal route for robotic drill route problem more often and at a faster rate than other proposed models, making it superior than other proposed models.

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