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Finding the Shortest Holes Drilling Path in Printed Circuit Board via the Dhouib-Matrix-4 Technique

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Abstract. The process of drilling holes in Printed Circuit Board presents a crucial issue and finding the shortest drilling path allows to minimize the movement of a robot arm in order to increase the productivity of the Computer Numerically Controlled Machine. In this paper, the novel metaheuristic Dhouib-Matrix-4 (DM4) is applied to find the shortest drilling tool path. DM4 is based on the combination of the novel constructive technique Dhouib-Matrix-TSP1 (DM-TSP1) and the original local search method Far-to-Near (FtN). Moreover, DM4 uses several differential statistical metrics in order to explore different regions in the domain space thanks to DM-TSP1 and exploits a specific region via FtN. The performance of the DM4 technique is evaluated against the Cuckoo Search, the Genetic Algorithm and the hybrid Cuckoo Search-Genetic Algorithm in finding the shortest drilling path for three standard problems.

Keywords. Artificial Intelligence, Simulation, Combinatorial Optimization, Metaheuristic, Computer Numerically Controlled Machine, Robot Arm, Manufacturing Process and Automation, Shortest Holes Drilling Path Problem.

1. Introduction

Finding the shortest holes drilling path in Printed Circuit Board is considered as a complicated process viewing the factorial correlation between the domain space and the problem size (for example, for a problem with a size equal to n there are $\left((n-1)!/2\right)$ realizable solutions). In fact, this problem can be considered as a Travelling Salesman Problem where the nodes are the cities and the salesman is the drilling robot arm: Thus, finding the shortest path between all cities for a salesman corresponds to drilling all holes by the robot arm.

This problem was investigated with several methods in the literature: The local search metaheuristic Far-to-Near is designed for the drilling path optimization in [1]. The Genetic Algorithm approach is developed to solve the holes drilling tool path problem in [2]. The Cuckoo Search, the Genetic Algorithm and their hybridization are investigated in [3]. The Optimal Foraging Algorithm is designed for finding the shortest drilling path in [4]. The Tabu Search method is used to minimize the total processing cost in [5]. The Particle Swarm Optimization technique is proposed to unravel the

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automated drilling operations in [6]. The path optimization problem is also optimized by the Ant Colony Optimization method for circular holes pattern [7].

In this paper, the novel Dhouib-Matrix-4 (DM4) technique [8-9] is employed to solve the drilling path optimization problem and its performance is proved through several standard case studies. Besides, the generated results will be compared to the results generated by the Cuckoo Search, the Genetic Algorithm and the hybrid Cuckoo Search-Genetic Algorithm.

2. The Novel Metaheuristic: Dhouib-Matrix-4

Actually in 2021, we have invented the concept of optimization named Dhouib-Matrix (DM) in order to solve combinatorial problems. For the Travelling Salesman Problem, the constructive heuristic Dhouib-Matrix-TSP1 (DM-TSP1) is introduced in [10-14]. Besides, for the Transportation Problem the greedy method Dhouib-Matrix-TP1 is designed in [15-17]. Hence, concerning the Assignment Problem the original Dhouib-Matrix-AP1 is presented in [18].

Basically, DM4 is a hybrid method gathering the constructive heuristic DM-TSP1 for exploration and the local search method FtN for exploitation. Hence, DM4 is iterated with two phases where the result of the first phase is used by the second phase as a starting point (see figure 1). In fact, the first phase executes DM-TSP1 with different statistical metrics (Min, Max, Average etc.) and the second phase starts FtN with the result generated via DM-TSP1.

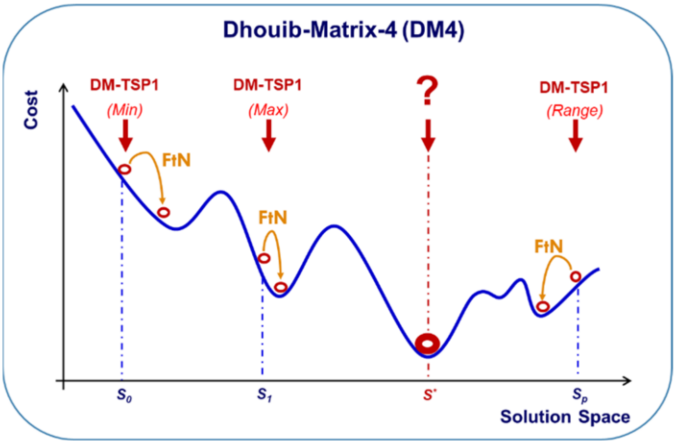

Figure 1. The searching strategies of the novel metaheuristic DM4

Fundamentally, the constructive DM-TSP1 is composed of four steps repeated (n-1) iterations in order to generate a cycle for the Travelling Salesman Problem (where the starting node is also the ending node: Hamiltonian cycle). However in this paper, DM4 is applied to look for the shortest drilling path and not a cycle, for that the last step (step 4) in DM-TSP1 is not considered (only the first three steps are executed). A step-by-step application of the DM-TSP1 method is described with details in [19-23].

Essentially, the local search method FtN is based on three simple structures: a prearranged selection of a neighbor, three methods to modify the current solution and an acceptation of a novel solution based on an original thresholding model (for more clarification see [1-24]).

3. Experimental Results

In this section, we will carry out three numerical simulations based on drilling holes (30, 50 and 75 holes) in a Printed Circuit Board (PCB) and using Manhattan distance in order to investigate the performance of the novel DM4 metaheuristic.

All the experiments were performed on Windows 10 operating system with a Processor Intel Core i5-321 CPU running at 2.50 GHz and 8 GB of RAM. DM4 is implemented in Python programming language.

DM4 will be compared to three metaheuristics developed in [3]:

- The Cuckoo Search (CS),
- The Genetic Algorithm (GA),
- The hybrid method (CS-GA).

3.1. Case Study 1:

This case study is taken from [3] with a 30 holes drilling problem in a PCB. The number of realizable solutions for 30 holes is exponential: $((n-1)!/2) = 4.42E^{30}$. DM4 found the best shortest path for this problem (49.739) where the CS found (52.598) and the GA as well as the CS-GA found (51.033). The best solution generated by DM4 is described in figure 2.

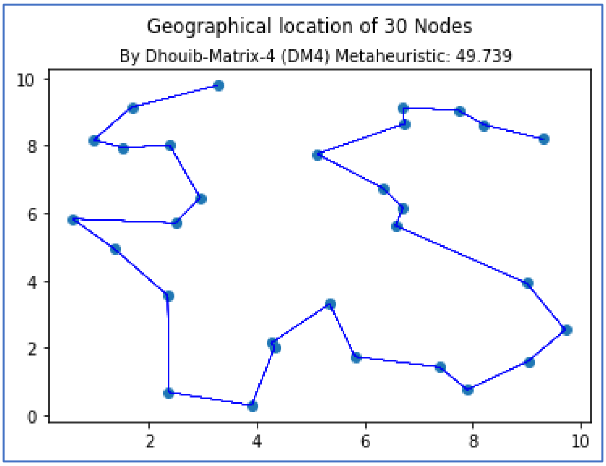

Figure 2. The shortest drilling path for 30 holes PCB created by DM4

3.2. Case Study 2:

The second case study presents a 50 holes drilling problem in a PCB taken from [3]. For this problem, there are $((n-1)!/2) = 3.04E^{62}$ realizable solutions. Again, DM4 found the best shortest path (67.991) where the CS found (75.465), the GA (68.605) and the CS-GA (68.299). The best solution found by DM4 is represented in figure 3.

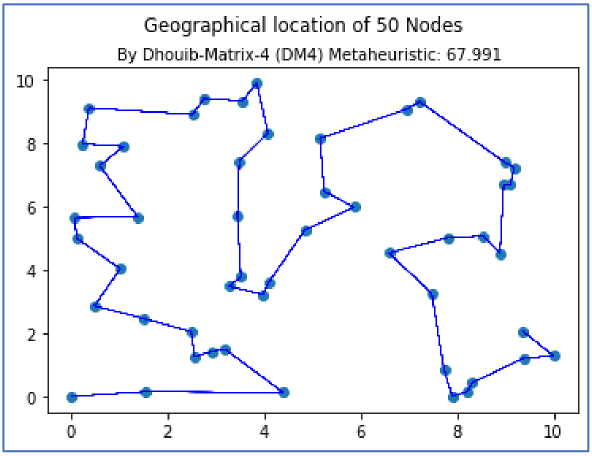

Figure 3. The shortest drilling path for 50 holes in PCB developed by DM4

3.3. Case study 3:

The third case study presents a 75 holes drilling problem in a PCB taken from [3] with a huge number of realizable solutions: $((n-1)!/2)=1.654E^{107}$. Also, DM4 found the best shortest path (80.756) where the CS found (120.604), the GA (85.079) and the CS-GA (80.799). The best solution produced by DM4 is depicted in figure 4.

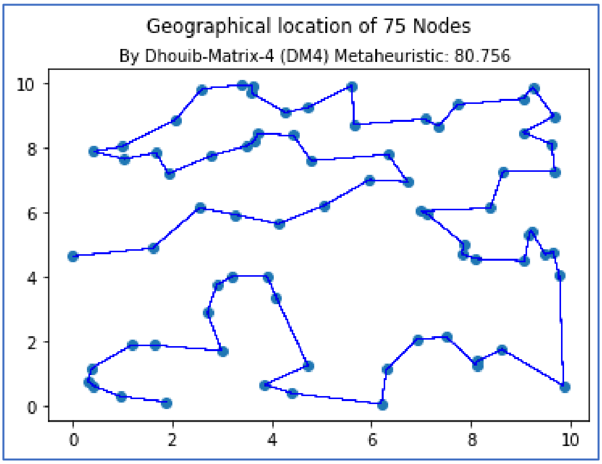

Figure 4. The shortest drilling path for 75 holes in PCB generated by DM4

4. Results

Table 1 summarizes the generated results (after 50 trials) by CS, GA, CS-GA and DM4 methods for the three drilling path optimization problems. The results demonstrate that DM4 improves the average and the best solutions for all instances. Moreover, the concurrent method to DM4 is the hybrid CS-GA with a total deviation error to DM4 of (0.828 %). Whereas, the GA found a closed solution to DM4 with a total deviation error of (3.139 %) and the CS generates a near solution to DM4 with a total deviation error of (25.282).

Table 1. Comparing the shortest drilling path generated by DM4 to those of the CS, the GA and the hybrid CS-GA

PCB case studies	CS		GA		CS-GA		DM4	
	Average	Best	Average	Best	Average	Best	Average	Best
30 holes	53.898	52.598	52.185	51.033	51.086	51.033	49.838	49.739
50 holes	79.270	75.465	70.479	68.605	69.412	68.299	68.998	67.991
75 holes	129.063	120.604	87.602	85.079	82.463	80.799	81.774	80.756

Figure 5 depicts the best result generated by each method for the three case studies (30 holes, 50 holes and 75 holes).

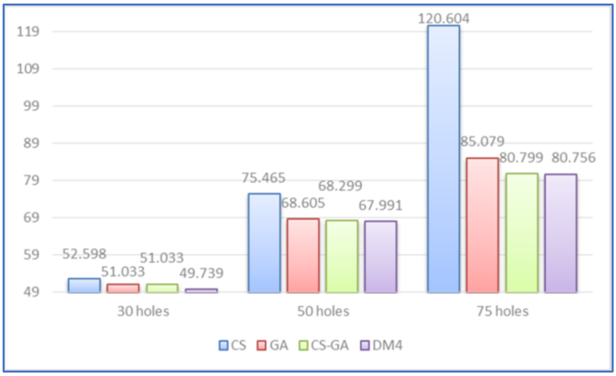

Figure 5. Comparing DM4 to CS, GA and CS-GA

5. Conclusion

In the present study, the novel metaheuristic Dhouib-Matrix-4 is proposed to find the shortest drilling path in a Printed Circuit Board for a robot arm. DM4 is a multi-start method based on the new constructive heuristic Dhouib-Matrix-TSP1 and the novel local search metaheuristic Far-to-Near. The experimental results prove the performance and the robustness of the novel technique DM4 to find the shortest holes drilling path. In further research, other applications of the novel DM4 metaheuristic on combinatorial problem will be tested such as the Milling and the Cutting Problems.

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