Multicriteria Optimization Ant Colony Algorithm for the Structural Elements Placement on the Printed Circuit Board

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***Abstract*— This paper presents the formulation of an optimization problem of elements placement on the printed circuit board. The choice of problem constraints and optimization criteria based on the structural, thermal and electromagnetic parameters of the PCB design is established. The description of the ant colony algorithm main procedures for solving the placement problem is given. The results of computational experiments on the ant colony algorithm effectiveness for solving the problem of elements placement on a printed circuit board are presented.**

***Keywords*— elements placement; printed circuit board; multicriteria optimization; ant colony algorithm; effectiveness parameters; controlled parameters**

I. Introduction

In case of the modern electronic means automated design, it becomes necessary to solve optimization problems with a high dimension of the baseline data, taking into account a large number (more than 3) of quality criteria and constraints. In the opinion of some experts, nowadays it is the multi-criteria automated design of electronic means that is in demand at the present time, that is because of the significant number of various designed objects requirements.

Most methods and algorithms for electronic means design are focused on solving single-objective problems. The application of these methods and algorithms for solving multicriteria problems requires its modification and additional studies. [1]

The purpose of this paper is to develop and study the effectiveness of the ant colony algorithm for solving the multicriteria problem of various-sized elements placement on a printed circuit board.

II. Placement problem formulation

The placement problem is to determine the coordinates x_i, y_i, for each element $e_i \in E$ (E – the set of placed elements, $i = \overline{1..n}$, $n=|E|$ – the number of placed elements) , the location of its geometric center within the printed circuit board assembly area with overall dimensions $A \times B$ ($0 \le x_i \le A$; $0 \le y_i \le B$), taking into account certain criteria and constraints.

In this paper, when solving problems of elements placement on a printed circuit board, a number of criteria are proposed: a minimum of the total weighted connectivity of the elements; as well as a thermal criteria and a criteria of electromagnetic compatibility (EMC).

The use of the first two criteria in case of the elements placement optimization, allows to minimize the connections length, which leads to traceability increasing (the percentage of the routed connections during the printed circuit boards routing stage). In addition, the connections length shortening leads to a reduction of the signal delays values in the interconnections, as well as to the electromagnetic radiation level decreasing and to improvement of the resistance to external electromagnetic influences.

As a thermal criteria, it is suggested to take into account the uniformity of the heat-loaded elements placement on a printed circuit board. Taking into account this criteria in the placement problem aids to reduce the elements operating temperatures and the overheating risk, which in turn leads to an increase in the electronic means fault tolerance.

To implement the EMC criteria [2–4] in this paper, the set of allocated elements is divided into groups (for example, by groups of elements: high-speed logical circuits; moderate speed logical circuits and analog circuits elements). A compatibility (incompatibility) relationship is established between the groups of elements. The belonging of an element to one of the groups, as well as each group EMC, is determined by the PCB designer. To ensure EMC, as criteria for the placement problem, it is proposed to minimize the distance between elements of one group, and also to maximize the distance between elements belonging to incompatible groups.

As design constraints of the placement problem, the following can be defined: minimum values of distances between neighboring elements; coordinates of fixed elements; forbidden zones of the printed circuit board, where the elements location is inadmissible.

III. Ant colony algorithm for placement problem

In this paper, to solve the problem of elements placement on a printed circuit board, it is proposed to use the ant colony

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algorithm [5–7], shown in Fig. 1 and based on the "block" decoder procedure.

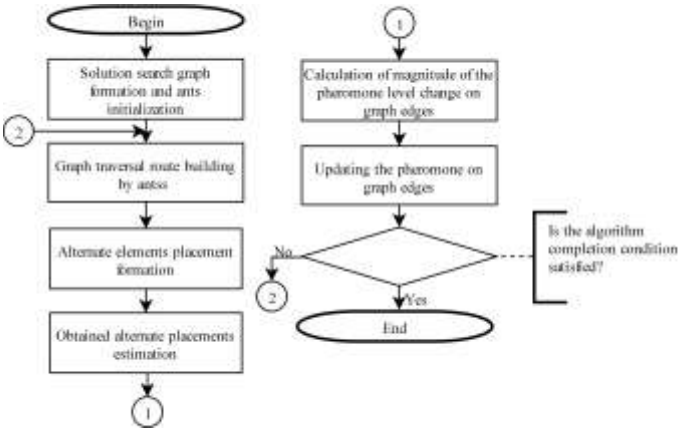

Fig. 1. Ant colony algorithm for elements placement on the PCB

The main idea of the ant colony algorithms is to simulate the ant colony behavior, while searching for the shortest path from the anthill to the food source. During the movement the ant marks its route with a special substance – a pheromone with a specific smell. So the information is transferred to other ants for choosing the path.

To implement the ant colony placement algorithm, based on the initial scheme of element connections, a complete solution search graph G is formed with alternative states of vertices. The vertices of the graph from the set H correspond to the elements of the circuit ($E \rightarrow H$), and the edges of the set U are the electrical connections of the elements. The edge weight is determined by the number of connections between the corresponding elements. To form a complete graph, in the absence of edges between some of its vertices, fictitious edges with zero weight are introduced. Each of the vertices of the solution search graph can be in one of two alternative states: zero or one. When the vertex is in zero state, the corresponding element is to be placed in a horizontal position on the printed circuit board, and in the case of a single state, in the vertical position.

The sequence of vertices, formed as a result of traversing the graph $G(H,U)$ by an ant, determines the order of elements placement on the printed circuit board. Thus, the solution of the placement problem resolves into finding the optimal route in the graph, taking into account the criteria and constraints.

Let us consider the basic steps of the ant colony algorithm for solving the problem of elements placement on a printed circuit board.

Step 1. The starting positions for the ants are determined at this step. In this case, all N ants are uniformly distributed over all vertices of the graph $G(H,U)$. The initial level of pheromone on all vertices (in every state) and edges of the graph is set equal to one.

Step 2. During this procedure, each k-th ant builds its route bypassing the graph $G(H,U)$, in accordance with the following algorithm:

1. The ant is placed in the starting top with number *cur*. In this case, all the remaining vertices of the graph are marked as not passed.

2. For the current vertex in the path c, the number cur is determined by the set $S_{cur} \in H$, the adjacent vertices of the graph, from the vertices not seen by the ant.

3. The probability of ant transition to each adjacent non-visited vertex of the graph (for two possible states of the graph) is determined by the formula:

$$p_{cur,j}(st) = \frac{(\rho_{cur,j} + w_j(st))^{\alpha} \cdot (c_{cur,j}+1)^{\beta} \cdot t_j^{\gamma} \cdot e_{cur,j}^{\zeta}}{\sum\limits_{\forall j \in S_{cur}} (2 \cdot \rho_{cur,j} + w_j(0) + w_j(1))^{\alpha} \cdot (c_{cur,j}+1)^{\beta} \cdot t_j^{\gamma} \cdot e_{cur,j}^{\zeta}},$$
$$\forall j \in S_{cur}, st \in \{0,1\};$$

where $p_{cur,j}(st)$ – is the probability of passing from the current vertex *cur* to the j-th vertex with the state *st*; $\rho_{cur,j}$ – level of pheromone on the edge between vertex *cur* and vertex j; $w_j(st)$ – level of pheromone on the j-th vertex in the state *st*; $c_{cur,j}$ – is the weight of the edge between the vertices *cur* and j (the number of connections between the corresponding elements); t_j – the index of thermal compatibility of the j-th element with neighboring elements (determined from the heat release power of the j-th and neighboring elements); $e_{cur,j}$ – index of EMC elements with numbers *cur* and j (determined on the basis of information about the belonging of the elements to a particular group and their compatibility); α, β, γ, ζ are the weights determining the priority of accounting for the levels of pheromones $\rho_{cur,j}$ and $w_j(st)$, as well as the values $c_{cur,j}$, t_j, $e_{cur,j}$ when selecting the next vertex in the ant path.

4. The next vertex in the path is determined using the "roulette wheel". A segment of unit length is divided into segments whose number is twice as large as the number of adjacent non-lasting vertices, $2 \times |S_{cur}|$. Each sector is associated with the number of an adjacent non-visited vertex from the set S_{cur}. The length of each segment is proportional to the value of the ant transition probability to the corresponding vertex taking into account its state. A random number is generated in the range from 0 to 1. The number and active state of the next vertex in the ant path is determined by the piece of the segment to which the random number belongs.

5. The ant moves to the next vertex. This vertex is marked as passed and becomes the current top in the path. The number of this vertex is assigned to *cur*.

6. If all the vertices of the graph $G(H,U)$ are visited (there are no missing vertices in the graph), then the transition to §2 occurs, otherwise, to §7.

7. The path formed by the ant is saved.

Items 1–7 are performed for each k-th ant in the population.

Step 3. Each route of graph $G(H,U)$ traversal, built on the previous step of the algorithm, corresponds to the alternate placement of the elements on the printed circuit board. In this case, the order of elements placement on the printed circuit board mounting pads determined by the sequence of vertices in the ant route. Filling of the printed circuit board mounting pad is carried out according to the levels, taking into account: elements dimensions and orientation, fixed elements, forbidden zones, distances between the elements, and other design constraints. Odd levels are filled in the direction from left to right, and even – from right to left. In Fig. 2 the alternate placement of the elements on the printed circuit board is shown, corresponding to the following sequence of the vertices traversing : 3, 6, 9, 4, 7, 1, 8, 2, 5.

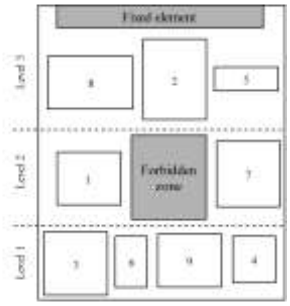

Fig. 2. Example of the elements placement on a printed circuit board

Step 4. The path formed by each *k*-th ant in the previous step of the algorithm is estimated by some value of the quality indicator F_k, calculated according to the problem objective function [8]:

$$F_k = \sum_{i=1}^{q} \lambda_i \cdot f_i \rightarrow min; \forall i = \overline{1..5}, 0 < \lambda_i < 1, \sum_{1}^{q} \lambda_i = 1;$$

where λ_i - are the weight factors, determining the importance of taking into account the *i*-th optimization criteria (it is established by the decision maker); f_i – is the normalized value of the objective function corresponding to the *i*-th problem criteria, q - is the number of the problem criteria. Then the path is determined that has the best quality indicator F^t_{best}, , among all the solutions built by ants during the algorithm work. This best path and the corresponding alternate placement are saved.

Step 5. For each path formed by the *k* -th ant, the magnitude of the pheromone level change $\Delta\rho^k_{i,j}$ on all edges of the graphs is calculated by the formula: the value $\Delta\rho^k_{i,j} = Q/F_k$, if the edge $\{i,j\}$ belongs to the *k*-th ant path and $\Delta\rho^k_{i,j}=0$ otherwise, $\forall i, j \in H, i \neq j, k = \overline{1..N}$ (where Q – is a constant that determines the order of the optimal solution price, N – number of ants in the population).

Similarly, we determine the magnitude of the pheromone level change $\Delta w^k_i(st)$) deposited on the graph vertices for each of two states. The value $\Delta w^k_i(st)=Q/F_k$, if the *i*-th vertex with the state *st* is included in the *k* -th ant route and $\Delta w^k_i(st)=0$ otherwise, $st \in \{0,1\}, \forall i \in H, k = \overline{1..N}$.

Thus, the better the *k*-th ant path, from the point of view of its quality index F_k, the more pheromone is deposited on its vertices in their active states and the edges of the graph.

Step 6. The level of pheromone on all graph *G(H,U)* edges is updated according to the formula:

$$\rho^{t+1}_{i,j} = (1-\mu)\rho^t_{i,j} + \sum_{k=1}^{N} \Delta\rho^k_{i,j}, \ i, j \in H;$$

where $\rho^t_{i,j}$ – is the current pheromone level on the edge $\{i, j\}$; $\rho^{t+1}_{i,j}$ – is the updated pheromone level on the edge $\{i,j\}$; μ - is the evaporation coefficient, $\mu \in [0;1]$.

Similarly, the level of pheromone is updated at all vertices of the graph, for each of the possible state:

$$w^{t+1}_i(st) = (1-\mu)w^t_i(st) + \sum_{k=1}^{N} \Delta w^k_i(st), \ st \in \{0,1\}, i \in H;$$

where $w^t_i(st)$ – is the current level of pheromone at the *i*- th vertex in the state *st*; $w^{t+1}_i(st)$ – is the updated level of pheromone at the *i*- th vertex in the state *st*.

Step 7. The transition to step 2 is carried out until the value of the change in the best route quality indicator $\Delta F = F^{t-1}_{best} - F^t_{best}$ (where F^{t-1}_{best} is the quality indicator of the best solution found in the previous iterations) will not exceed a certain threshold value ε over a certain amount the last iteration.

Usually, most ants line up in the colony, following one shortest path, at the last iteration. The best way, built by the ants at the last iteration, corresponds to the resulting optimal alternate placement of the elements on the PCB.

IV. Research results

Introduced ant algorithms for solving the problem of the elements placement on a printed circuit board was implemented in MS Visual Studio programming environment , in the C # language. Using the developed program, experimental studies on the effectiveness of the developed algorithms were carried out. As baseline data for experimental study, a number of examples were developed, representing the schematic diagrams of real digital electronic means and differing in the dimension of the baseline data. In this paper, the following experimental studies of the ant algorithm for solving the placement problem were performed:

1. Comparative studies on the effectiveness of ant, evolutional, greedy and blind search algorithms [9–12] for solving the problem of elements placement on a printed circuit board. Within the scope of this experimental study, the quality indicator of the solutions obtained using various placement algorithms was estimated. The solutions quality indicator was determined by the value of the additive objective function. Table 1 presents the results of experimental studies on the various algorithms effectiveness for solving the placement problem, taking into account EMC and thermal compatibility criteria.
2. Study of the dependence of the solutions quality parameters and the effectiveness of the ant colony algorithm on the controllable parameters values for solving the placement problem. The ant colony algorithm efficiency is determined by its convergence rate. To estimate the convergence of the ant colony algorithm, the number of generations (iterations) was

recorded, during which the magnitude of the best solution quality change ΔF exceeds a certain threshold value ε. The experimental controlled parameter of the ant colony algorithm was chosen the dimension of the ant population. The obtained dependence of the ant colony algorithm convergence rate values on the population size is shown in Fig. 3.

TABLE I EXPERIMENTAL RESULTS

№	Number of elements placed	The quality index of solutions obtained by			
		Ant colony algorithm	***Evolutionary algorithm***	***Greedy algorithm***	***Blind scan algorithm***
1	27	13578,95	14374,34	14548,21	14492,68
2	32	38367,62	40119,76	43062,33	45669,02
3	46	61233,44	63234,61	65539,45	64906,98
4	51	99645,32	103526,42	109660,65	112623,71
5	63	393848,12	413234,22	425437,52	428478,98

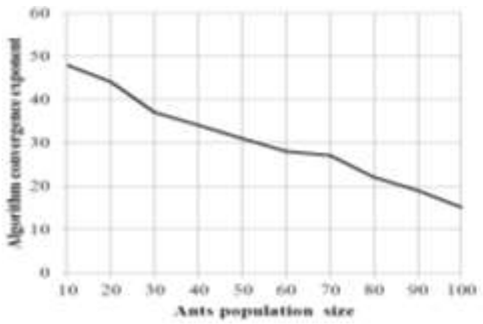

Fig. 3. Dependence of the ant colony algorithm convergence on the population size.

V. CONCLUSIION

Based on the experimental studies, the following conclusions are proposed in the paper:

1. Ant colony algorithms exceed other considered placement algorithms (evolutionary, greedy algorithms and blind search algorithms) by 5–7% in terms of the quality of the solutions obtained.

2. The convergence rate of the ant colony algorithm increases with the growth of the ants population.

The experimental estimation of the developed ant colony algorithm time complexity is in the range O (n^2) – O (n^3). The use of the additive objective function to convolve the problem partial criteria and the ant colony algorithm provides an acceptable quality of the Pareto approximation of solutions

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