THE CURRENT STATE OF SCIENTIFIC RESEARCH IN THE FIELD OF OPTIMIZING PRINTED CIRCUIT BOARD PROCESSING TECHNOLOGIES BY MINIMIZING DRILLING PATH USING GENETIC ALGORITHMS

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ABSTRACT: *This article will present the current state of scientific research on the optimization of printed circuit board processing technologies, by minimizing the path of the processing tool using genetic algorithms. Detailing the general aspects and basic principles of printed circuit boards, the research stage of the traveling salesman problem and the association of the problem of path minimization at drilling process of printed circuit boards and the improving methods of the process regarding the determination of the minimum length of the optimal path.*

KEYWORDS: *printed circuit boards, genetic algorithms, optimization, traveling salesman problem*

1 INTRODUCTION

The remarkable technological impact that took place in the field of printed circuit boards, after the middle of 20th century, with the application of modern industrialization in the manufacturing processes, the production of PCBs has an upward direction. If we group together, as a unique characteristic, the efficiency and effectiveness of a PCB, today's trends tend towards a high complexity and productivity, through minimal manufacturing costs. The balance between complexity/ productivity and manufacturing costs is directly influenced by the technological process of drilling the boards (Ancau, 2009).

The sudden evolution of printed circuit boards has had a visible result in the evolution of electronic products, considering the high demand for products and their rapid optimization in all areas. Usually, the manufacturing of boards is done in mass, in large manufacturing batches, and small and unique series are rarely made, usually in the case of prototypes. For a simpler perspective, printed circuit boards are found in all electrical products around the world, in all fields, not just technological ones.

Printed circuit boards are complex products due to the multitude of functions that can be performed simultaneously and very quickly. A PCB is designed to make connections between electronic components through the paths created in the copper conductive layer. The boards represent the physical platform for mounting and interconnecting electronic components such as processors, transistors, capacitors, diodes, etc., and the way the drilling paths are designed and optimized can have an impact on performance, reliability and production costs.

Optimizing PCBs is an important aspect in their evolution, both for improving performance and the cost/profit ratio.

Over the years, much research has been gathered on PCBs. Most of them being oriented on the drilling technological process. Due to the time required to move the tool from one point to another, the problem of minimizing the route when drilling printed circuit boards has drawn attention in the field of research and engineering to try to obtain an optimal solution compared to the initial one. In specialized articles, in the case of the drilling process, making holes of different sizes by changing the tool and positioning for each hole separately, represents a necessary time of [50% - 70%] of the entire operation. For a PCB to be able to compete on the market, cost reductions are necessary, most of which are directly derived from the manufacturing process (Lim *et al*, 2014).

All these optimization problems of minimizing the length of the path between the holes made by the cutting tool, are very easily associated and integrated with the TSP-Traveling salesman problem or well-known like (heuristic, Euclidean, symmetric problem).

In the research to solve the traveling salesman problem, algorithms are developed with solutions that use constructive principles on the route, known as "tour construction approaches". Another optimization method is the improvement algorithms, or "Tour improvement approaches". They are local search methods for large-scale problems. Main role in improving the quality of the route.

The main purpose of the article is to present the current state of scientific research on the optimization of the process of drilling printed circuit boards. In addition to the introductory part related to the design of the PCBs and the development of the route problem, the article contains improvement methods for this problem. The types of algorithms and how they work on a population will be described.

2 PCB's DESIGN ASPECTS

Printed circuit boards are presented as the brains of an electronic circuit within any object of this kind. Geometrically, it is a flat component made of an insulating intermediate layer on which conductive paths are engraved on the outer layers, electronic components being mounted at each end of the path. The optimal design also consists in the correct management of the space on the board, through the orderly placement of the electronic components and at the same time the functional realization of the electrical flow between the components.

The scientific study of printed circuit boards is a complex process, detailed and attentive to the understanding of their structure and functionality. It also involves rigorous testing to ensure functionality, quality and current technological trends in the market. With various applications in industry, medicine, communications and others, the field of PCBs offers a complex perspective on modern electronics and its continuously expanding evolution.

2.1 Manufacturing of PCB

Design. The design of the electronic circuit is carried out in specialized software programs CAD (Computer Aided Design), in the electronics industry known under the acronym EDA (Electronic Design Automation), being specialized programs for electronic components. The technological factors that have a major impact on PCB design are mechanical, electrical, functional and environmental.

Listed below, the design elements that are considered when developing a printed circuit board:

- Circuit type: analog or digital;
- Board size;
- Number of layers (insulating layers and conductive layers);
- The size of the PADs (the stiffened area of the conductive element);
- The size and number of the holes;
- The layer's thickness;
- Connectivity with electronic elements.

Layer lamination. Lamination of layers. Successive layers are created by the lamination or printing process, by applying thin copper foils on the surfaces of the insulating board. Before the application of the conductive layers, resins are impregnated on the insulating layer, and through polymerization they increase the mechanical resistance of the layer. After drying, the next step consists in applying the copper layers through electrolytic processes for fixing the metallic material.

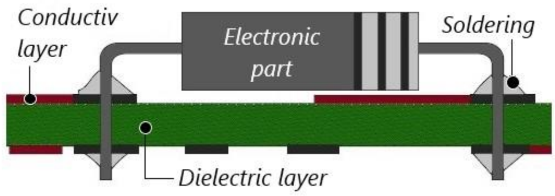


Fig. 2.1 PCB's layers section view

The insulating layer is the base plate, made of a flexible or rigid material, made of epoxy resins with suspensions of glass fibers. In some cases, Teflon substrates, ceramics and special polymers are also used. The conductive layer is generally made of thin sheets of high purity copper. By laminating the copper layers, thicknesses between 0.03 ÷ 0.035 [mm] can be reached, obtained by the processes: electrodeposition, by anode-cathode or classic rolling with micro-rolling.

Surface etching/ erosion. In certain areas of the Copper surface, it is necessary to remove the material in a controlled manner, using two methods (Mitzner, 2007):

- Wet acid etching;
- Mechanical milling/drilling;

Through the wet acid etching method, the PCB is completely contained in the corrosive solution, by removing the weak copper layer. The corrosive solution being alkaline ammonia or cupric chloride. The mechanical process is carried out with the help of CNC (Computer Numerical Control) machines, by chipping the copper layers. The major advantage being the fact that the removal of the material is controlled according to requirements.

PCB drilling. The drilling process can be carried out by multiple methods, classic or modern. Each of the procedures has advantages and disadvantages, depending on the use and the type of plate. The main mechanical drilling processes are:

- Punching;
- CNC drilling;
- Laser drilling.

Soldering electronic components. Resistors, transistors, integrated chips, diodes, etc., are mounted in the holes on the final board. They are welded in place on the PADs around the holes, then the fixing paste is applied, a soft aluminum alloy that becomes liquid at the average working temperature. The welding of the components is done by melting the welding paste with infrared, hot steam or applying heat to the legs of the components until the paste melts.

Testing, control and finalization. After the completion of the assembly stages, the PCB is cleaned, checked and subjected to tests to verify the connections and the way of working as a full assembly.

2.2 PCB's classification

The classification of printed circuit boards can be determined according to a wide variety of individual characteristics and attributes, as well as including a large technological area of use. A classification according to the class of quality and utility are:

- *General consumption plates*, used on a global scale, the main characteristic being given by the low manufacturing price;
- *Professional ones*, used in advanced products with multiple work functions;
- *High reliability*, found in military and research applications, where the superlative of a product is sought.

A different classification, made according to the technical specifications of the board, has the great advantage that it refers directly to the structure of the board (Gutin *et al*, 2004):

- **Single-sided PCBs**. The name refers to the fact that the connections of the electronic components to the board are made on one side of the dielectric layer, also called "solder side", and the surface of the components being "component side". It is the most used PCB model in all fields of the world.
- **Double-sided PCBs.** This type of board has the electronic components glued on both sides, the electronic contact and the rigidity of the legs being increased. Double-sided tiles are also divided into two categories, **non-PTH** and **PTH (Plated Trough Hole)**. In the case of non-PTH boards, without connection through the plated hole, the costs are minimal, and the bonding is done only where necessary. PTH plates, with plated holes, practical consists of metallizing the hole for a better and stable connection. Most PCBs being of this type.

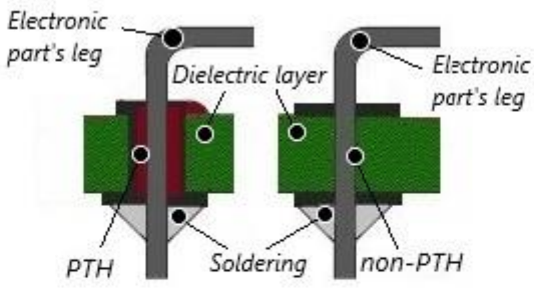


Fig. 2.2 PCB's layers section view

- **Multi-Layers PCBs.** Multilayer PCBs appeared following the discovery of problems with previous models. Problems related to noise, loss of capacity and voltage drops in the case of the signal from the parallel lines. Multilayer boards are easy to program, necessary for large populations of electronic components.
- **Stiff and flexible PCBs.** The classification is made according to the type of material of the dielectric layer. The rigid PCBs are made of conventional materials, while the flexible ones are made of polyesters and polyamides that allow the flexibility of electrical circuits. The material with elastic properties used on a global scale represents only 10% of the total PCBs manufactured in the world.

The evolution of electronics is continuously on the rise, which will have an impact on manufacturing technologies by increasing complexity. Moreover, through the high demands for products and the desire to increase the speed and computing power for each individual PCB, it's making this field to be in continuous research and development. Soon, the trend is to make interconnectivity between products through "wireless" technologies. Here, the automation technology through the necessary high computing powers will be supplemented by ultramodern PCBs capable of the industry 4.0 domain.

3 ROUTING PROBLEM. TSP

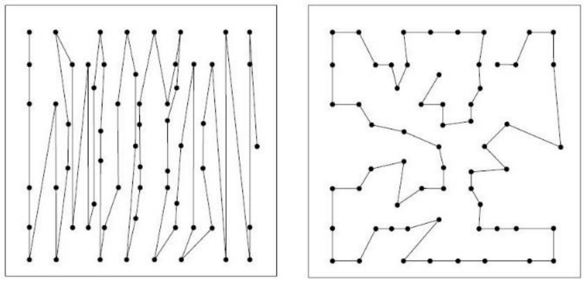
Traveling Salesman Problem or the TSP represents an important role in the field of problems known as *combinatorial optimization problem.* The TSP belongs to the class of NP-complete problems or NP-hard problems. They are part of the Hamiltonian circuit type problems, due to the way of intersecting the route through all the existing points, only once, the exception being the first and the last point. The studies of this problem started as far back as the 19th century, and the association between the traveling commission problem and the problem of minimization of the path when drilling a PCB consisted in the fact that they evolved over the years simultaneously and have the same characteristics in principle, a number of points , which requires the shortest possible route between them.

Definition for TSP: Having a number of cities and the distances between each one, TSP represents the study of finding the optimal possible solution to visit all the cities, and to return to the initial one, by minimizing as much as possible the total route distance. The main problem is finding the route with the shortest length.

A challenge that makes this problem better studied refers to the possibility of obtaining a large number of routes, until finding the optimal one. As the number of stopping points (cities) increases, more permutations between nodes are required, resulting in more improved but different variants. When the movement can be made directly from one node to any other in the population, the final graph can be called a complete graph.

For this general problem, two broad problem categories have been classified: ***(Symmetric Traveling Salesman Problem - STSP)*** and **(*Asymmetric Traveling Salesman Problem - ATSP)*.**

In the symmetric STSP model, it is considered that the distance from one point to the next is equal to the distance traveled in the opposite direction. In the asymmetric model there can be no symmetry, leading to two different routes between points. The possible number of routes in the case of ***n*** cities to visit are ***(n-1)!*** for ATSP and ***(n-1)! /2*** for STSP (Greco, 2008).



a) b)

Fig. 3.1 Example of nodes and paths distribution for a TSP: picture a) is a free path distribution and picture b) is an optimized path distribution

Fig. 3.1 represents two route options. The points are the nodes (cities) that represent the population number ***n***. Representation **a)** shows the definition of a random, unfavorable route, and in case **b)** an optimized route is represented between the population of nodes.

The research done on these types of problems, *combinatorial optimization problems*, shows that there are two possible methods of solving by implementing a general genetic algorithm: the method of obtaining a global solution on the population, and the second one being the implementation of evolutionary algorithms, which can transmit solutions very good or even optimal. Tour construction methods and tour improvement methods are used as principles for solving the traveling salesman problem. These methods are called **Heuristic methods**, appellation from Greek literature *Heuriskein* meaning *search/ discovery/ analysis.* (Ancau & Camilleri, 2007).

Throughout the studies, simple variations have emerged from the original TSP version having connections in daily life or in various related applications (Gutin, 2004): Max TSP, Bottleneck TSP, TSP with multiple visits (TSPM), Clustered TSP, Generalized TSP (GTSP), m-salesman TSP.

The basic principles that lead to the association stage between the two topics discussed, TSP and printed circuit boards, are:

- the main element that performs the action, the cutting tool and/or the salesman, travel a route through a number of ***n*** points, resulting in a tour following the movement;
- both are similar in that they feature a number of points that require sequential intersections in each node, (hole/city), all under minimal cost;
- the greater the number of stopping points, the greater the tendency to use heuristic

algorithms, due to the multiple variants of obtained solutions that need to be optimized.

Regarding the application of TSP in the context of minimizing paths for drilling printed circuit boards, it can be presented as a specific variant of the problem, where the aim is to find an optimal path for making holes for interconnecting electronic components. The aim is to minimize as much as possible the costs involved in the process and to reduce the interference of the trajectories made by the cutting tool.

Applications. A concrete example is in the case of route planning for vehicles, where an evolutionary algorithm was proposed for the parameterization and detailing of available routes in relation to real-time traffic conditions (Zheng J *et al,* 2022).

Once the problem of the traveling salesman began to gain traction in research studies, associations with other problems in researchers' lives began to emerge. The fields of applicability have a major number, in medicine, aviation, the electronic field and problems of traffic or courier management (Davendra, 2010):

- PCB drilling;
- X-Ray crystallography.
- Computer wiring.
- Overhauling gas turbine engines.
- The order-picking problem in warehouses.
- Vehicle routing;

4 IMPROVING METHODS

Presented previously, as an overview, there are two major heuristic approaches for determining a minimum route, **“*tour construction approaches*”** (simpler, **constructive methods**) and **“*tour improvement approaches*”** (**improving methods**) (Davendra, 2010).

At the same time, in order to be able to analyze the performance of the mathematical algorithms used and to make critical analyzes between them, the method of calculating the lower limit is used, **Held-Karp lower bound.** This common way of testing new algorithms develops a lower bound on the optimal solution, generally 0.8% below the optimal round, where it directly analyzes the evolution and performance of the algorithm. For a detailed study of H-K, a research study reference is made (Khatiwada *et al*, 2020).

Constructive methods, “*tour construction approaches*” they include algorithms that have as a major disadvantage, the fact that once a solution is found they will not try to improve it. They stop calculating and display the result. They are algorithms used in much simpler and faster calculations. These constructive algorithms are found under the names below:

- *Nearest Neighbor* – is the simplest constructive method. Within the TSP, the movement from the initial node to the next one is done on the closest next node.
- *Greedy heuristic*;
- *Christofide*;
- *Clarke*-Wright;
- *Intersection heuristic, etc*.

```
… end (condition not satisfied)
>>
▪ Generate random permutation of n holes;
▪ Setup a partial tour with the first three, four, …,
  holes from the above permutation;
▪ Insert holes (nodes) in the tour, based on the
  condition of minimum tour length increasing;
▪ If the condition above is not satisfied, select next
  holes number from the second line;
>>
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Fig. 4.1 A short example with steps for a tour construction approach method
(rewritten after (Ancau, 2009))

Improving methods ”*Tour improvement approaches*”, are local search methods that are used on large-scale problems, with the need for detailed calculations. The improvement algorithms, as soon as they have generated a heuristic of a route, they start improving the quality of the route, the process continuing until a notable result is obtained.

```
… end (condition not satisfied)
>>
▪ Improve the tour using 2Opt, 3Opt, etc. method;
▪ Check, remove and rebuild crossing segments;
▪ Calculate the tour length;
▪ If (actual tour length < prev. min. tour length)
      min. tour length = actual tour length
>>
```

Fig. 4.2 A short example with steps for a tour improvement approach method
(rewritten after (Ancau, 2009))

These route improvement methods are efficient and accurate within large populations of individuals, but with the need for a longer calculation time.

Over the years, numerous calculation methods have been developed on the optimization of various problems by minimizing routes, costs and manufacturing times. A main and useful tool in the case of these problems are genetic algorithms.

Genetic Algorithms. Studied over a long period of time, genetic algorithms are used as tools in solving many problems related to general combinatorial optimization. In particular, they are used for NP-complete type problems, previously presented in chapter 3. The definition being its own name, genetic algorithms are heuristic methods, designed according to the evolution theories of Charles Darwin. The fundamental principle of evolution consists in the survival of the strongest individual.

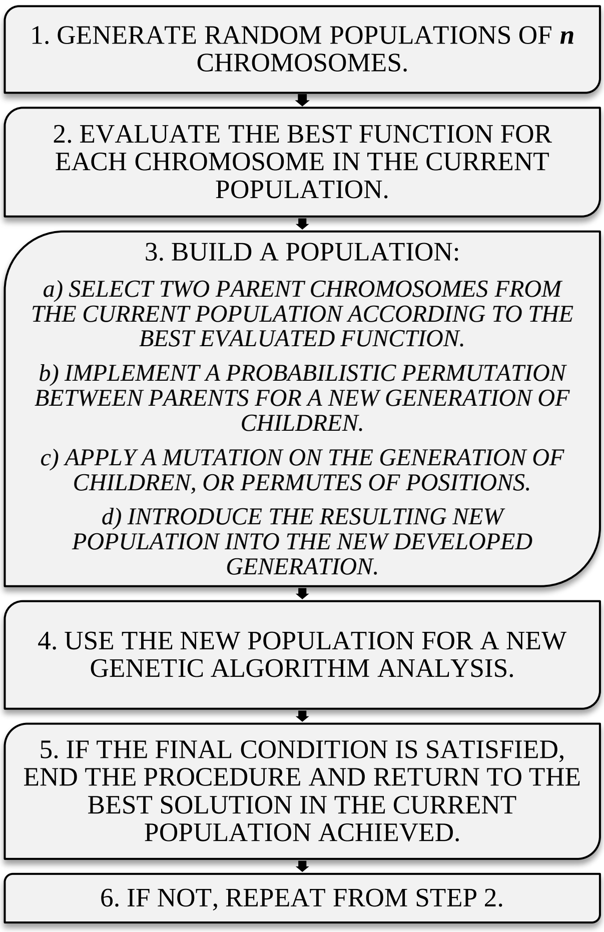

Fig. 4.3 Genetic algorithms stages, making new populations

According to the presentation above, the development of genetic algorithms is based on Darwinist evolutionary theories, the main tools for the development of a population being ***"natural selection"***, genetic mutations and permutations/ combinations between genes (*individuals*). The application of genetic algorithms - GA to the TSP involves multiple sequences in the selection of the population, its measurement, the implementation of the mutations and crosses created on the algorithm and restarting the process if the conditions imposed within the program are not met.

5 CONCLUSION

This article presents the current state of research on minimizing the path for drilling printed circuit boards.

The first part of the article presents the theoretical study of printed circuit boards, where general principles, optimizations on manufacturing technologies and future trends on the efficiency of the drilling process are presented. The second part of the article shows theoretical concepts regarding the traveling salesman problem (TSP), derivatives of the problem and everyday applications where the solution of this general problem can be applied to the problem of PCBs.

The fine theoretical information with improvement methods in the minimization of the path of connecting nodes, on TSP problems, among the types of genetic algorithms classified into two large categories, the constructive ones and the improvement ones.

The field of research includes vast information related to the problem of path minimization when drilling printed circuit boards by using genetic algorithms. Thus, at the basis of the design of a genetic algorithm that can be applied to combinatorial optimization problems, are the scientific research in the field, with a major role in generating an overview to be able to know the current state of the research, being the main goal.

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