Automatic verification of design rules in PCB manufacturing*

João Ramos[1], Patrícia Rocha[2], Flávio Vilarinho[2], António Silva[2], Marcos Andrade[2], João Varajão[2], Luis Magalhães[2], Pedro Ribeiro[3], and Luis César Freitas[3]

[1] Centro Algoritmi, University of Minho
Department of Informatics, Campus de Gualtar
Braga 4710-057, Portugal
jramos@di.uminho.pt,
[2] Centro Algoritmi, University of Minho
Department of Information Systems, Campus de Azurem
Guimarães 4804-533, Portugal
{b7673,b7232,b7216,b7963}@algoritmi.uminho.pt
{varajao,lmagalhaes}@dsi.uminho.pt
[3] Bosch Car Multimedia Portugal, SA, Portugal
Braga, Portugal
{pedro.ribeiro2, luis.freitas}@pt.bosch.com

Abstract. Nowadays, electronics can be found in almost every available device. At the core of electronic devices there are Printed Circuit Boards (PCB). To create a suitable PCB there is the need of complying with several constraints, both concerning electrical and layout design. Thus, the design rules related to the PCB manufacturing and assembly are very important since these restrictions are fundamental to ensure the creation of a viable physical PCB. Electrical Computer Aided Design (ECAD) tools are able to automatically verify such rules, but they only consider a subset of the total required rules. The remaining rules are currently manually checked, which may increase the occurrence of errors and, consequently, increase the overall costs in designing and in the manufacturing process of a PCB. Being the design a crucial phase in the manufacturing procedure, a software system that automatically verifies all design rules and produce the corresponding assessment report is fundamental. Such software system is addressed in this paper.

Keywords: Printed Circuit Board · Design Collaboration · Rule-based Design · Data Exchange.

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1 Introduction

In today's industry, considering the electronics area, one may consider the PCB the most common way of assembling electronic circuits [4]. These are made by one or more insulated layers in which several elements, like capacitors, resistances, and coils, are inserted. There are also copper patterns that connect these elements. The position of the elements is fundamental for the correct functioning of the PCB since these may cause various forms of errors into a circuit due, for example, to the electromagnetic interference or the heat that a component may induce in other. Thus, despite placing the elements in a PCB, designers must pay special attention to the electrical characteristics since these may interfere in the performance of the PCB, specially when considering high precision or high speed PCBs.

A successful development of a PCB may usually be seen as a PCB with a long living period. However, to achieve such goal there is the need of maintenance, repair and overhaul (MRO) services that must be provided by the manufacturer [13]. In the maintenance domain there are three identified applications, namely functional testing, obsolescence management and redesign processes. The former is related with the identification of errors and malfunctions, which is achieved through inspection processes. The obsolescence management defines the period, based for example on mathematical formulas, in which the manufacturer will keep a stock of spare parts of will give repair solutions for existing PCBs. The later addresses overhauling processes where the initial PCB layout may be adapted, modified or completely redesigned. In this step, outdated components must be replaced by renewed developments. This is used whenever a potentially appropriate spare part is obsolete [13]. The MRO processes of electronic devices are specially challenging in companies that have long-term products like aviation industry, rail transport or plant manufacturing [7]. The functionality of a PCB must be tested and possible faults must be detected and repaired. When facing an obsolete PCB and there are not any spare parts available, redesign is the only alternative, which may be time consuming and have high costs.

To avoid the completely redesign processes after the manufacturing process and to reduce MRO services that may be needed, a good PCB layout design must be assured.

The manufacturing process of a PCB includes different stakeholders, which includes multidisciplinar teams that may be internal teams of the company, but also external teams that may manufacture the PCB and assemble its components. There is also the possibility of having internal teams over different countries according to the affiliates of the company. Each stakeholder has his own interest in particular parts of the PCB design and use different data to validate the design. The correct exchange of information is extremely important [12] in order to maintain a good involvement of all parts.

Despite the features of ECAD tools, the number of rules and constraints that need to be manually verified is high. Indeed, these tools are not able to completely check the conformity of the PCB design and layout. Some of these rules have to be manually verified by a company collaborator, which may lead to deviations in the design. The design rules are usually structured in extensive documents and may be difficult to assess. The non-verification of all design rules does not prevent the physical manufacture of the PCB. However, when not considering the machinery constraints in the design rules, the large scale production may be compromised, since the robotic arm that, for example, assembly a component may not have sufficient room to operate. The existence of standards or ontologies to define the design rules may be considered an important step for the layout design since it may structure every required rule.

In this paper it is described a tool that is able to automatically verify the rules for producing the PCB. The non-conformity of the PCB with the rules does not mean that the PCB may not be physically produced. The conformity with the existing rules assure that the PCB may be mass produced by the company using the existing machinery.

This paper is organized as follows: Section 2 presents a short review on PCB design, specifically in the data exchange between different teams. Section 3 briefly describes current practices for modeling rules. In Section 4 is presented the system that automatically verifies the layout of the PCB according to the defined guidelines. Finally, in Section 5 the main conclusions are drawn.

2 PCB design

Considered as the basic component in the electronic products, the design of a PCB is extremely important since it also allows for a modular architecture of the products. The large scale production of a PCB is preceded by a design and evaluation phases where the layout of the PCB is defined and tested in order to assess if it complies with the company guidelines. This process involves several stakeholders and each one evaluates different aspects of the PCB. Figure 1 is a schematic of all partners involved in the layout design. Indeed, the exchange of information between team is crucial, but, due to the assessed features, the type of format used by each may significantly vary. Indeed, as Abrantes et al. describe in [3], there is a large set of formats which, if not correctly transmitted and treated, may led to the loss of information when sending the results from one team to another.

Abrantes et al. [3] studied and compared different ECAD file formats considering the PCB objects and their properties. Despite the development of neutral ECAD files formats, there is still a low adoption of such standards by ECAD tool vendors [6]. Thus, there are, for example proprietary ECAD file formats, IDF (Intermediate Data Format) [9], IDX (Incremental Data eXchange), STEP AP210 [10], ODB++ [1], and IPC - 2581 [8]. Abrantes et al. [3] concluded that there is a lack of standardization and the attempts to create one have failed since they were not adopted by ECAD tool developers.

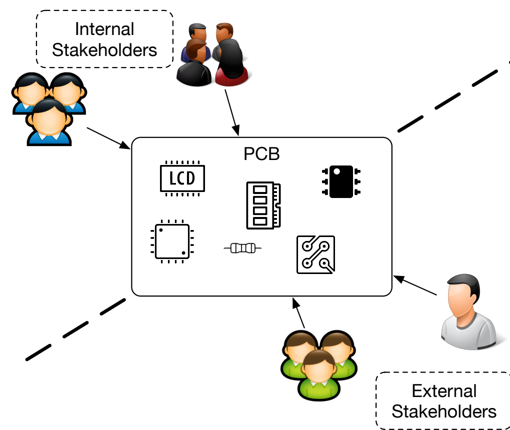

Fig. 1. Schematic of teams (internal and external to the company) involved in the PCB design process

3 Rule modeling

Design rules for manufacturing process define the set of constraints that need to be checked and met in order to produce a PCB. These rules, primarily defined under the form of check lists have been progressively converted and included in automated processes through CAD/CAM systems. According to the specificity of the analysis of the PCB, the development of such rules is usually limited to software tools that included them in a hard coded manner. There are also other proprietary approaches like the one developed by Boeing [10] or Samsung [11]. Here, the rules are coded and the applications/systems developed in accordance with the necessities and specificities of each PCB.

As described by Abrantes et al. [2] there are different rule-based practices according to the application domain. Indeed, the lack of a standardization due to, for example, companies competitiveness, turns the development of ECAD tools to be domain specific (Figure 2). In [2], the authors developed an ontology through which they were able to convert the process rule documents into rules written in natural language form. Though the definition of this ontology the rules have to be written with the same structure, removing possible deviations when one tries to read and understand long and exhaustive documents. This ontology was previously created by the research team and through it an ECAD tool (described in Section 4) that automatically verifies the PCB layout design is being developed. This systems improves the verification coverage that is currently supported by the adopted ECAD tools and reduces the need of human inspection.

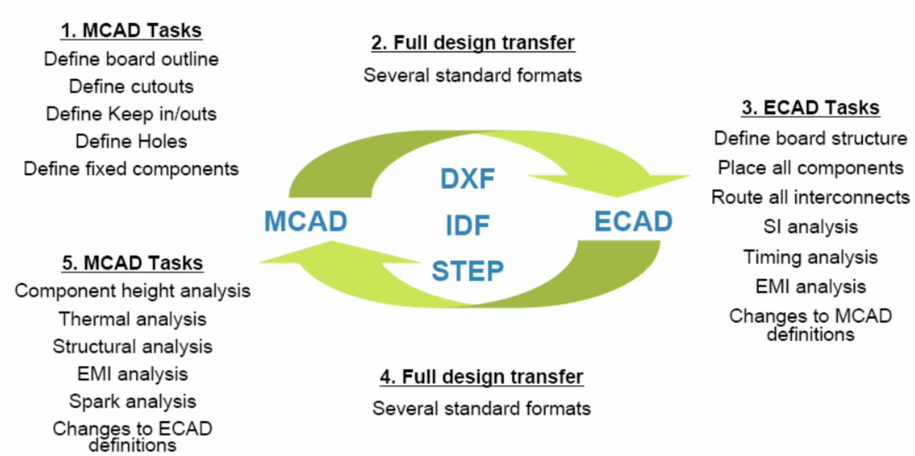

Fig. 2. Concurrent engineering between ECAD and MCAD, retrieved from [5]

4 Rule assessment tool

The manufacture of a PCB is preceded by a complex and long process involving multiple stakeholders, which may be part of the same company or from an external one. This process, the design of the PCB, needs a collaborative activity over these different teams since each deals and assess different parts of the PCB. For this process there are multiple tools that, with the information stored in a database or inserted by the operator, assist in the decision process by providing an analysis of the PCB design. The exchange of information between Mechanical Computer-Aided Design (MCAD) and ECAD is essential to ensure the correct design of the PCB [10,5], but the lack of a standardization turn this a hard process.

The integration of ECAD/MCAD may be seen as being complementary to each other, since electrical design may be dependent on the mechanical one and vice-versa. Indeed, the physical layout is a balance between the space available between components and the mechanical constraints, considering the size of the components of the PCB [5].

Considering the physical layout of the PCB it is important to ensure that the available machinery is able to manufacture the designed PCB. To this process there is a large set of constraints that have to be met. The developed assessment tool may be fundamental to support the decision of the engineer since it may evaluate a large set of constraints in the PCB layout, i.e., before creating the physical PCB.

Adopted ECAD/MCAD tools by the company, in which the rule assessment tool is under development, allow the parametrization of some parameters in the pre-existent rules. However, these rules are mainly focused in the PCB concept, i.e., in assessing if the PCB that is being developed will operate correctly. Available tools may not consider the design constraints and the mass production of such PCBs may be compromised since the user cannot manually add such particular manufacturing constraints. Through the rule assessment tool one, according to the authorization levels, may add design rules considering not only the clients' requisites, but constraints related to the available machinery.

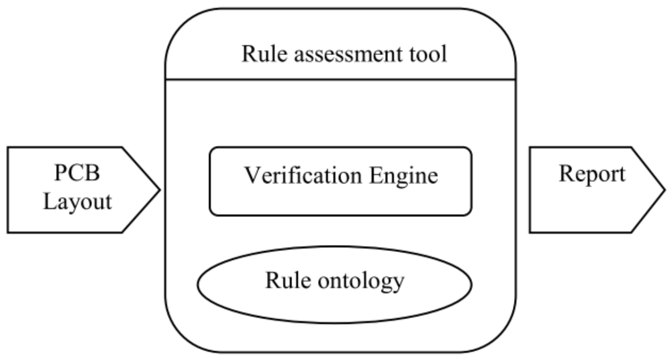

Fig. 3. Overview of the rule assessment tool, extracted from [2]

Figure 3 presents an overview of the rule assessment tool. During the design phase of the PCB the engineer inputs the current PCB layout into the system that, considering the rules defined through the ontology and the verification engine, verifies if every component, with respect to that PCB, is in accordance with the defined guidelines. After the verification process, the tool generates a report identifying the guidelines that are violated. Using the rule assessment tool the iterative process of designing a PCB may be reduced since a higher number of violated guidelines is identified in earlier stages of the development process. The overall costs may also be reduced since the human error is mitigated and possible deviations are identified before the physical production of the PCB.

To increase the functionality of the tool and also to better understand and create guidelines, there is a rule ontology that establishes the parameters of the guidelines. This may also be seen as a standardization of existing guidelines, removing possible mistakes in existing documents due to, for example, a missing necessary parameter that had to be defined. The rule ontology as been defined in [2]. The rule assessment tool provides a graphical user interface to generate rules considering the defined ontology. It is assumed that all rules may be represented using the same ontology.

The example depicted in the Figure 4 establishes the ontology for the distance rule category. In this case the user has to define the distance between elements, stating that it must be, for example, equal (conditional operator) to 5 (value) mm (measurement).

5 Conclusion

The PCB design is essential for a successful manufacturing process. Indeed, being this one of the basic component of electronic devices, it is of the most importance that when produced in a large scale, the PCB respects all constraints and all

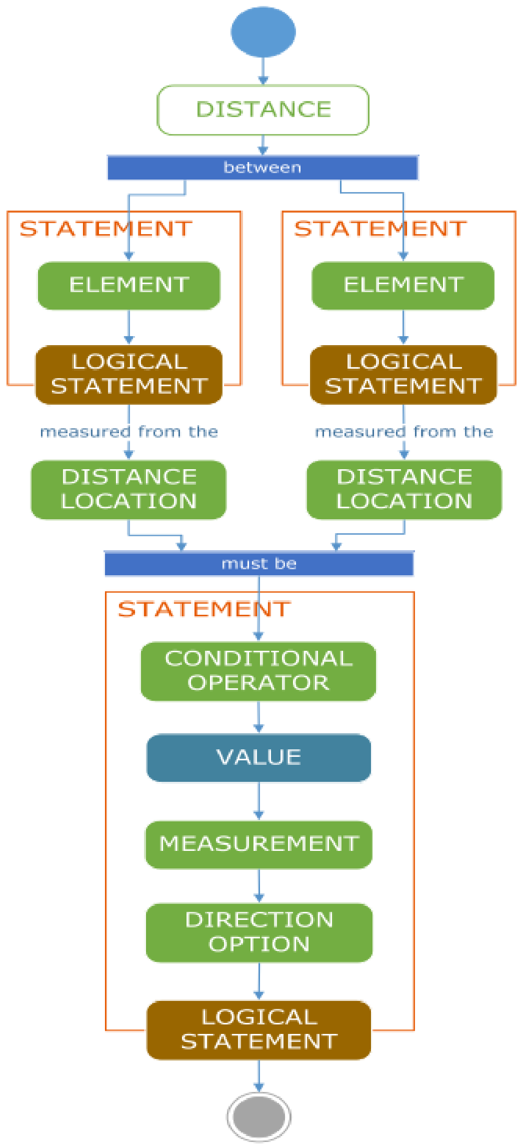

Fig. 4. Distance rule category model, retrieved from [2]

rules regarding its manufacturing process. When one or both situations occur, then the producing costs will increase due to scrap or to rework to rectify the already produced PCBs.

ECAD tools assist in the electronic design and automatically check a set of design rules with respect to the available guidelines. MCAD tools are also an important set of tools since through them is possible to establish the physical layout of the PCB. However, the exchange of information between these different tools, even when considering several ECAD tools, may not be an easier process due to a lack of data standardization and proprietary software. Indeed, not all rules are automatically verified by such tools and there is the need of a human visual inspection. This manual process is prone to human error, which may increase the manufacture process due to the late detection of a deviation.

With the development of the assessment tool there is a double goal: develop an ontology and automatically verify the PCB guidelines. With the former is possible to ensure that all guidelines are identically structured, leading to a standardization inside the organization. This may also reduce deviations when reading and interpreting existing documentation. Through the later is possible to assist in the PCB design since a broader set of rules is automatically verified in the design process, i.e., before the PCB manufacturing process. Thus, using the assessment tool the stakeholder may take better decisions since the system indicates which guidelines are not met or which component locations should be checked. The human error is reduced since the number of checked rules is greater and, consequently, the overall costs are reduced.

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