Computers and Chemical Engineering 39 (2012) 163–169

Contents lists available at SciVerse ScienceDirect

Computers and Chemical Engineering

journal homepage: www.elsevier.com/locate/compchemeng

A large-scale statistical process control approach for the monitoring of electronic devices assemblage

Marco S. Reis[a,*], Pedro Delgado[b]

[a] CIEPQPF, Dept. of Chemical Engineering, University of Coimbra, Rua Sílvio Lima, 3030-790 Coimbra, Portugal
[b] Bosch Car Multimedia Portugal, SA, Portugal

ARTICLE INFO

Article history:
Received 24 January 2011
Received in revised form 5 December 2011
Accepted 13 December 2011
Available online 21 December 2011

Keywords:
Printed circuits boards
Principal components analysis
Multivariate statistical process control
Receiver operating characteristic

ABSTRACT

In this paper, we present a new procedure for monitoring the assembly process of electronic devices. Monitoring the status of this operation is a challenge, as the number of quality features under monitoring is very large (order of thousands) and the number of samples available quite low (order of dozens). We propose an efficient approach for the on-line and at-line monitoring of such a process, by addressing two, hierarchically related, problems: (i) detection of faulty units (printed circuits boards with abnormal deposits); (ii) given a faulty unit, find a candidate set of solder deposits responsible for the anomaly. Our methodology is based on a latent variable framework using PCA for effectively extracting the normal behavior of the process. Both the variability in the PCA plane and around it (residuals) are considered. We have tested the proposed approach with real industrial data, and the results achieved illustrate its good discrimination ability.

1. Introduction

The assembly of electronic devices usually consists of a sequence of stages performed with highly automated machinery under well controlled environmental conditions, in order to produce functional units at high rates. In this work, we focus, in particular, in the initial stages of these processes, where typically thousands of solder paste deposits (SPDs) are placed over printed circuits boards (PCBs), in a fast and accurate way, at different and specific positions, in order to support and functionalize the electronic components that will be added at a later stage. Despite the high production rates achieved in these processes, the cost associated with each unit under processing may be economically significant and increases steeply as the product moves forward in the assembly line. Therefore, any malfunction in a unit under processing must be promptly signaled and analyzed for its relevance, according to well defined criteria, after which a decision must be made concerning its acceptance or rejection. Furthermore, if a faulty pattern emerges on the successive units being assembled, it must be quickly corrected, in order to drive the process back to the desired operational conditions, before a large quantity of defective products is produced. However, several important problems emerge in this context.

Firstly, in the assembly process, several thousands of solder paste deposits (SPDs) are placed at specific positions in the printed circuits boards (PCBs) (Fig. 1). They will hold and connect all the electronic components that will be added at a later stage. In our case, the fixation process is accomplished through "reflow" soldering. The shape of the deposits (SPDs) varies significantly and is dependent upon the types and sizes of the components to be fixed and functionalized. Such shape plays a central role in the proper constitution of the solder joints for each individual component and, ultimately, on the reliability of the whole electronic device. Therefore, one can easily recognize the importance of simultaneously monitoring the shape and position of all the SPDs that are placed in each PCB. The problem, of course, is that such a task encompasses the simultaneous analysis of several thousands of SPDs.

The second problem has to do with the low number of samples available for implementing a statistical process control (SPC) approach for this problem, in order to assist operators in the identification of abnormal samples. Statistical process control is a family of methods focused on bringing and maintaining the process in a stable state of operational conditions, close to the desired target (the so called "normal operation conditions", NOC). A process in such a stable condition is said to be "in statistical control", i.e., subject only to "common" causes of variation (Montgomery, 2001; Shewhart, 1931). The most well known class of SPC tools are the control charts, which aim to signal those situations where some sort of abnormality or problem arise in the process, called "special" or "assignable" causes of variation, in the jargon of SPC. Control charts consist of graphical procedures where the NOC region for the monitoring statistics, computed from data collected from the process, is confined by control limits, meaning that any point plotted beyond such a region should be signaled as a potential abnormality.

* Corresponding author. Tel.: +351 239 798700.
E-mail addresses: marco@eq.uc.pt (M.S. Reis), pedro.delgado@pt.bosch.com (P. Delgado).

0098-1354/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compchemeng.2011.12.008

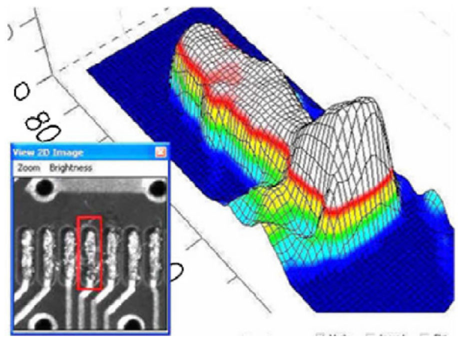

Fig. 1. Several solder paste deposits (SPDs) in a printed circuit board (lower left), along with a three-dimensional profile (larger image in the background), obtained through Phase Moiré Interferometry, regarding a solder paste deposit (SPD) with some shape problems (the SPD is the one signaled with a rectangle in the lower left image).

Such reference lines (the control limits), are estimated from data collected in a period where the process is operating under a state of statistical control, and are placed in such a way to provide a good coverage of the situations classified as "normal" (usually a coverage of 99% or higher is adopted).

In the present situation, the most problematic period occurs at the beginning of each new production run, where the process parameters are not all optimized and fine tuned. This period is also the one where normal operation data is still scarce, implying that one is left with a problem of having to estimate the NOC region of a very high dimensional process, from a rather limited number of samples.

However, in our case, the setup process of the proposed methodology can be speeded up through the application, to each SPD, of a set of rather general and conservative acceptance rules, involving the different geometrical measurements available for each SPD (height, area, volume, offset in the XX' coordinate direction and offset in the YY' coordinate direction). These rules to be applied to each SPD, vary according to the type of component to be connected at a later stage. Such a procedure was developed by the plant engineers after carefully analyzing the patterns of variability in a large number of PCBs, from which it was noticed that the dominant source of variability in the data collected for each geometrical feature, was the shape of the components. Therefore, individual rules were developed for each type of component, which are currently being applied to analyze each and every SPD in a PCB.

This procedure has been proved to be good enough for initiating the production processes, as well as exhibits the nice feature of being transferable to other similar facilities, using the same assembling machines, but it still presents some limitations that hinder the full exploitation of all data available. For instance, not only its development is very time consuming, but also it fails when components with new geometries are introduced in the assembly process for the first time. Furthermore, it tacitly assumes that the shape measurements for every SPD are statistically independent, being only parameterized by a set of population parameters that depends upon the type of component they fix. In other words, the current procedure considers, for instance, that the "normal operation conditions" (NOC) variability of the shape parameters for a given type of component, say A, fixed in a corner of the PCB, is the same as when it is fixed in the central part of the same PCB. This is the same type of hypothesis considered quite often in wafer inspection activities during the production of integrated circuits, where defects are assumed to follow a Poisson distribution, which tacitly implies that the probability of defects is the same everywhere in the wafer and all defects are independent of each other (Montgomery, 2001). However, if vibrations and random displacements are continuously affecting the successive PCBs passing through the assembly line, their impact should manifest differently according to the position of A in the PCB (namely, due to rigid body rotational movements), along with a certain degree of correlation linking both sets of measurements. In this context, a spatial-dependent source of variation is expected to emerge in the data collected, meaning that the hypothesis according to which, shape measurements for every SPD are statistically independent, may not be viable. In these conditions, one should not treat each SPD as a univariate random event, but all the measurements of SPDs in each PCB as a single realization of a large scale multivariate stochastic process.

By taking such large scale dependency into account, one can improve the sensitivity of the current methodology for detecting small and medium size changes in the solder deposits shape. However, the challenge to be addressed in this case is, of course, how to properly define the multivariate NOC model with the few "good" samples initially available, in order to begin implementing SPC as soon as possible.

Finally, a third important aspect to consider in the analysis of the present problem, is that everything must be implemented very efficiently, as the operator has less than 1 min to decide what to do, after a unit is signaled as potentially faulty.

In the work presented in this paper, we go beyond the conventional approaches centered on the monitoring of defect rates which are based on rather simplified assumptions, such as independence between the occurrences of defects in different positions, while exploring all the measurements made available simultaneously by the image acquisition system. This means that our methodology is able to deal directly and simultaneously with all the SPDs applied to each printed circuit board (in our case there are 3084 such deposits) in order to come up with an improved approach for detecting whether each unit (PCB) under inspection is "normal" or "abnormal" and, if this happens to be so, to point out which deposits are potentially causing the abnormality.

This article is organized as follows. In the next section, we describe the measurements collected from the process and present the proposed methodology for addressing the two hierarchically related problems referred above. Then, the results obtained regarding the implementation of this methodology in a real world scenario are presented, in order to illustrate its validity and potential usefulness in practice. Finally, we discuss some aspects of the proposed approach and summarize the main contributions of our work, as well as refer some interesting future work to be carried out, built upon the framework developed so far.

2. Materials and methods

2.1. Dataset

A total of 31 records were collected from the process for analysis, each one of them concerning a different unit under processing (PCB). Each record contains all the information acquired in a routine way in the process (using "Phase Moiré Interferometry"), for a PCB, in particular, the height (h), area (a) and volume (v) for each one of the 3084 SPDs, as well as their positioning offsets in the X and Y directions, relative to target points in the reference coordinate system, amounting to a total of $5 \times 3084 = 15{,}420$ measurements for each PCB unit. The measurement process is rapid and rigorous enough for in-line implementations, taking about 15–20 s to produce a complete assessment of all solder deposits contained in a PCB.

From the set of 31 records, 15 were classified as "good", whereas the remaining 16 presented different kinds of problems that originate, according to the assessments performed in the operations floor, a final classification of "fail". These problems arise from