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Improving operator evaluation skills for defect classification using training strategy supported by attribute agreement analysis

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A R T I C L E I N F O

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A B S T R A C T

Automatic Optical Inspection (AOI) machines have an important role in the monitoring and detection of errors during the manufacturing process of electronic circuit boards. These machines show images of products with potential assembly defects to an operator and let him decide whether the product has a real defect or on the contrary it was an automated false positive detection.

The attribute agreement analysis methodology is part of a Six Sigma strategy to examine the repeatability and reproducibility of an evaluation system, thus giving important feedback on the suitability of each operator in classifying defects.

In order to reduce the number of operator errors, a training method was developed with the support of the attribute agreement analysis method with test images presented to operators for classification.

By using this methodology, it was possible to check the capability of each operator, and improve the operator's evaluation score. After the application of the tool, the improvement of results is shown.

1. Introduction

Quality improvement projects are often characterized by their objective to reduce variability and achieve zero-defect production. If a product fails to conform to these standards, analysts generally blame the process and then act to improve process capability [21,23].

The growth of global competition in the electronics industry has increased the importance of the company's ability to respond to ever changing customer demands. Thus, the time required to design, develop and manufacture was reduced to achieve cost reduction, increased reliability, quality improvement and sustainability. Thus, some companies are implementing a variety of different techniques to find solutions for reducing the development cycles, and to adjust the business with the market requirements [7]. Due to the differences in the measures used by the sellers and buyers, conflicts sometimes arise. To resolve these conflicts, standardized measures of length, volume, and time were invented. Since then, various instruments have evolved with ever-increasing precision [12,22]. Quality includes not only statistics, control chart, or sampling plan, but also training, personal quality and customer satisfaction [8,26]. Quality is seen as a win-win situation for customers and manufacturers. The customer has all the interest in the correct functioning of product and for as long as possible. The manufacturer also has an interest in it, because it creates or maintains a high reputation, besides minimizing the costs associated with the production. Conti [6] argues that all the competitors have access to the same techniques, technologies and skills. The real differentiating factor is to create an organization that is able to set out winning objectives and meet them (obviously through an intelligent use of all existing technologies). According to Dedhia [8], the customer is king. The customer is not dependent on the manufacturer, but instead it is the manufacturer that is dependent on the customer. As the importance of customers grew, customer satisfaction measurements came into existence. On the other hand, according to [32], service quality is regarded as the key factor in obtaining competitive advantage. Thus, according to Teboul [28], quality is the ability to satisfy the needs or wants at the time of purchase or during use, ensuring the minimum possible cost, minimizing losses, and doing better than competitors.

During the Surface-Mount Technology (SMT) process, several images are captured and analysed by machine algorithms. In the event of possible errors, the machine shows to the operator which components may be defective, and the operator decides whether it is a real defect or a false error, commonly referred to as a machine pseudo-error. One of the problems in this phase is related to the number of defects detected by the machine that are not correctly evaluated by the

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operators. This problem is due to several factors, namely the constant evolution of electronic components wherein the components have new shapes. Another problem is the high turnover of operators on the production line, being that each production line has its specific products and as such, some lines have their own exclusive components. This process requires a continuous improvement, realized through regular evaluation and training.

Attribute agreement analysis, or Attribute Gage R&R, is based on the analysis of the same samples by different operators. Each operator classifies these samples, and the samples are repeated two or more times, in a randomized experience. This type of analysis allows the evaluation of the correlation between the assessments made by the appraisers (operators) and the known standard. One can use the Attribute Agreement Analysis to determine the accuracy of the assessments made by appraisers and to identify which items have the highest misclassification rates [17]. According to [25], with the use of an attribute agreement analysis study, it is possible to reduce or to eliminate the impact on the subjectivity of the quality judgment done by operators.

This paper presents a case study of applying a statistical measurement methodology (Attribute Agreement Analysis) to improve manufacturing production quality through the implementation of a new training system and evaluation of operators in automatic optical inspection (AOI) machines.

2. Measurement systems

In a process that is integral to a measurement system, some variation is likely to occur. Measurement system analysis is an important area of study that is able to determine the amount of variation. In evaluating a measurement system's variation, the most adequate technique, once an instrument is calibrated, is Gage repeatability and reproducibility (GR&R) [21]. Vágó & Kemény [29] states that for an attribute measurement system, the measured process parameter is categorical. Hence, every statistical activity for quality, such as acceptance sampling, quality control, and quality improvement, depends on measurement. Consequently, knowing the capability of measurement systems is important. Gauge repeatability and reproducibility (R & R) studies are experiments that assess the capability of measurement systems [4]. Shi et al. [27] argue that Gauge repeatability and reproducibility studies are important to guarantee the validity of data, which is essential to other researches. A small variability of a series of measurements is a good indicator of repeatability, meantime the reproducibility is associated with the stability of a measurement process [35].

According to Weaver et al. [34], the precision of a measurement system needs to be assessed before using it in any activity that uses measurements, like acceptance testing, statistical process control, and quality improvement experiments. A Gage repeatability and reproducibility (R&R) study is used to assess a measurement system's (i.e., gauge's) 'capability' by determining how much of the observed variability in any of these applications can be attributed to the Gage, as well as how large the components of the measurement variation are. The variability in a measurement system is usually decomposed into two components, known as repeatability and reproducibility, which are generally associated with the variation arising from the equipment and the variations caused by different operators (appraisers) using this equipment [10]. Repeatability refers to the measurement variation under fixed conditions (e.g., same part, same Gage, and same operator, often thought of as 'within-operator' variation). Reproducibility, which can broadly refer to the variation in testing equipment, time and operator, refers to operator-to-operator (or between operator) variation for this study. Thus, Browne et al. [3] argues that operators are often thought to be a substantial source of variability in a measurement system. Each operator is assumed to have a different mean when repeatedly measuring the same part so that there are relative biases among the operators. Hence, the main objective of a measurement system is to effectively detect the variation of a process in order to correct this variation. Thus, according to [31] the repeatability and reproducibility (R&R) study—also called a Gage capability study—has been employed as part of the statistical process control program in many organizations. Practically, a measurement system does not always produce the exact dimension of the part, but it gives measurements that are deviated from the true value by some error [1]. Shi et al. [27] states that Gauge repeatability and reproducibility (R&R) studies are significant to quality improvement and quality control. Sometimes the measurement system does not give the correct measurement of the part (in this case the operator).

The AIAG suggests in its measurement systems analysis Manual [2], that to effectively manage change in any process, there must be knowledge of what the process should do, how the process should do it, and what can be wrong. These measurements are used for a variety of purposes, such as to determine whether the process is adequately controlled, for implementing procedures to control the process, or whether the process is capable of meeting customer requirements, for increasing the understanding of the process, to model the process, to characterize the manufacturing of the product, to perform sampling inspections, etc.

There are several types of Gage R&R studies that can be performed, being the two most common studies the Gage R&R for variables and the Gage R&R for attributes [24]. Each of these studies should be applied considering what is to be measured. The study with variables can only be applied to measure the variation of numerical quantities (length, width, height). For a study by attributes, the measurement objectives are based on qualitative values, for example: 'good/bad' or 'pass/fail'. The Gage R&R study for attributes makes it possible to verify the capability of the SMT process. These studies are being conducted faithfully in various industries, involving the abundance of data generation, training in statistical methods, and data analysis using statistical software [19]. The Gage R&R for attributes study is based on the analysis of the same samples by different operators. Each operator classifies these samples, and the samples are repeated two or more times, in a randomly experience.

According to [25], with the use of a study of Gage R&R for attributes, it is possible to reduce or to eliminate the impact on the subjectivity of the quality judgment by operators, but their assessment is

Table 1
Kappa values.

Kappa values	Agreement level
0.90–1.00	The system of measurement is excellent.
0.70–0.89	The system is capable, but can be improved.
0.50–0.69	The system is bad, needs to be improved.
0.00–0.49	The system is unacceptable.

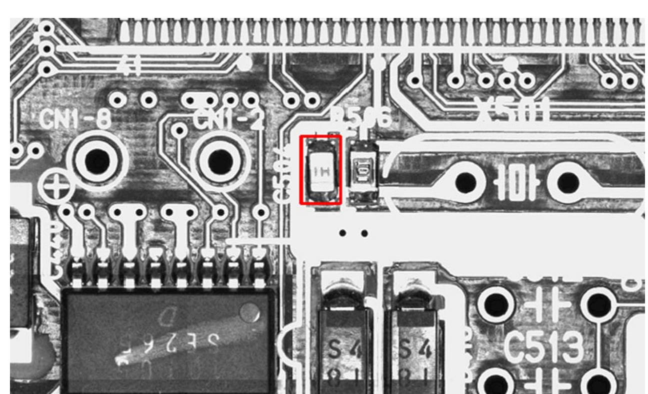

Fig. 1. Image captured in grey-scale [30,16].