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Multivariate measurement system analysis in multisite testing: An online technique using principal component analysis

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ABSTRACT

Multisite testing improves manufacturing throughput and reduces costs by applying simultaneous testing to products with multiple measurement instruments in parallel. It is important to perform measurement system analysis (MSA) on a multisite testing system to assess its testing capability. Traditional MSA methods are designed to be either univariate or multivariate in a single-site system. They are not capable of analyzing a complex multisite testing system where there are multivariate measurements and multiple instruments in parallel. We propose an online multivariate MSA approach to detecting faulty test instruments in a multisite testing system. In order to pinpoint a faulty test instrument in a multisite testing system we compare the performance of each test instrument to the overall performance of all the parallel instruments in the system. A modified principal component analysis (PCA) method is proposed to transform multivariate measurement data with dependent variables into those with independent principal components. Assuming that all the instruments have the same measurement accuracy and precision we consider a faulty instrument as one whose principal component values are beyond the three sigma control limits of the principal component values of all instruments. We conduct an experiment to provide empirical evidence that the proposed approach is capable of identifying the faulty instruments in a multisite testing system. This approach can be implemented as an online monitoring technique so that production is not interrupted until a faulty instrument is identified.

1. Introduction

Multisite testing, also known as parallel testing, refers to the simultaneous testing of products using multiple measurement instruments in parallel (Goel & Marinissen, 2005; Khoche et al, 2001; Kramer & Proskauer, 2005; Ma & Lombardi, 2008; Rivoir, 2004). The semiconductor Automatic Test Equipment (ATE) industry often utilizes multisite testing to reduce test cost and improve production throughput. An ATE is an automated testing device that examines products ranging from simple electronic components (e.g., resistors) to complex electronic devices (e.g., smart phones). It applies a multivariate test vector to a Device-Under-Test (DUT) in order to examine its quality characteristics and identify faulty devices (Hashempour, Meyer, & Lombardi, 2005; He, Luo, & Shi, 2006). An ATE only tests one product or subcomponent at a time, leaving expensive test hardware and resources idle more than 50% of the test time (McDonnell, 2006). Multisite testing typically shares a set of test hardware across multiple ATEs. Therefore, it can improve manufacturing throughput without spending money to duplicate test hardware.

Measurement system analysis (MSA) is a systematic procedure that identifies the components of variations in the precision and accuracy assessments of measuring instruments used in a measurement system (Niles, 2002). The purposes of MSA are to: (1) determine the extent of the observed variability caused by a test instrument; (2) identify the sources of variability in a testing system; and (3) assess the capability of a test instrument (Burdick, Borror, & Montgomery, 2003). MSA is an important element of *Six Sigma* as well as the *ISO/TS 16949* standards. It examines five types of statistical variations, including the commonly used Repeatability and Reproducibility (R&R). In the field of quality assurance the goal of MSA is to determine if a measurement system satisfies the quality assurance requirements. Existing R&R MSA measures, including the precision-to-tolerance ratio, signal-to-noise ratio, discrimination ratio, and confidence intervals, mainly examine the R&R of univariate measures. When applied to a multivariate testing scenario, these measures would only provide partial information because they do not take into account the correlation or dependency that often exists between multivariate variables (Hayter & Tsui, 1994; Nedumaran & Pignatiello, 1998). Multivariate statistical methods, such as the principal component

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analysis (PCA) and cluster analysis, have been proposed and applied to quality engineering practices that involve highly correlated multivariate measures (Lowry & Montgomery, 1995; Yang & Trewn, 2004). However, those methods have never been applied to multisite testing where the variations among the parallel instruments add another layer of complexity on top of measure correlation and dependency. In multisite testing a product is randomly assigned to one of the parallel test instruments assuming that those instruments have the same statistical distribution characteristics in measurement variations. But in reality characteristics such as mean and variance will vary across different instruments as common cause variation is expected in any process. Quantifying the expected level of variation, the common cause variation could facilitate the identification of a faulty instrument as the characteristics of its statistical distribution would be expected to be different. In practice it is difficult to identify the faulty instrument unless we take the production offline and calibrate each instrument from time to time. Taking production offline is very time-consuming and cost-bearing due to the interruption to production. Consequently an online method of evaluating the instruments that reduces the interruption of production processes is preferred. To the best of our knowledge there is limited research related to measurement system analysis in multisite testing.

In this paper we propose a PCA-based approach to multivariate measurement system analysis in multisite testing. This approach provides for the in-process monitoring of all instruments and considers a faulty instrument as one whose statistical distribution of measurements differs significantly from the overall distribution across multiple test instruments. We define control limits so that a faulty instrument can be identified and taken offline for calibration when the performance of the instrument goes beyond the control limits, indicating the presence of special cause variation.

The rest of the paper is organized as follows. Section 2 provides an introduction to multisite testing. Section 3 introduces existing MSA techniques and their shortcomings. Section 4 proposes the PCA-based measurement system analysis method in multisite testing. Section 5 presents an empirical experiment and results. We provide a conclusion in Section 6.

2. Multisite testing

A multisite testing system, such as the one illustrated in Fig. 1, has multiple test instruments in parallel where each test instrument independently examines multiple quality features for a DUT. A product unit or subassembly coming from the preceding manufacturing processes is randomly assigned to one of the test instruments. Tested units are merged back together before entering succeeding manufacturing processes. Multisite testing, especially in the semiconductor ATE industry, is often used to collect multivariate quality measures at each site to maximize testing system efficiency. Multisite testing has benefits when compared to traditional sequential testing methods. It has been shown to be an effective method for reducing test costs as multiple devices are tested in parallel (Rivoir, 2004). Additionally, multisite testing greatly improves test efficiency and production throughput. McDonnell (2006) showed that a multisite testing system with four parallel testing instruments and auto scheduling increased the usage of testing hardware by as much as 40% and production throughput by almost 50% comparing to a traditional sequential testing system (McDonnell, 2006). In addition, Ma and Lombardi (2008) demonstrated that multisite testing achieved 54.66% reduction in test time over a single-site method. Lastly, multisite testing provides great flexibility in test planning. As manufacturing processes are continually challenged to become more agile, lean, and flexible, it is of great benefit for manufacturers to be able to easily adjust the settings of a multisite testing system to match the changed production and testing requirements and consequently provide optimal test efficiency with the lowest cost. The number of parallel test sites can be increased or decreased as dictated by production volume. In the case of a production decrease, the idle test instruments can serve as back-ups to those instruments that become faulty due to friction and attrition.

An online quality monitoring system is necessary to detect faulty test instruments in multisite testing. All instruments in multisite testing are expected to have the same level of measurement accuracy and precision after the initial instrument set up. However, uncertainty in measurements can be introduced by many factors such as the differences in instrument operators and wear-out development. It is difficult to distinguish the faulty measurements caused by a defective instrument from those measurement variations caused by the normal differences across operators, DUTs, and instruments. It is also difficult to pinpoint a specific defective instrument because post-test DUTs are merged together and immediately enter subsequent manufacturing processes. One could calibrate each instrument from time to time, however, this would interrupt the production and increase cost. An online quality monitoring system is always desired in order to reduce human intervention and cost in highly automated manufacturing processes. Such a monitoring system not only monitors the quality of product parts, but also diagnoses the causes of the detected quality problems. This allows quick fixes to be executed automatically to prevent further problems. When automated fixes are not possible, the real-time online monitoring system should at least pinpoint the problem cause and support decision making for field experts. Lin and Lee (1989) showed that a real time measurement system significantly improved operational efficiency and labor reduction for quality control and production control.

3. Measurement system analysis and multivariate measurements

The purpose of measurement system analysis (MSA) is to "separate the variation among devices being measured from the error in the measurement system" (Larsen, 2003). Most statistical

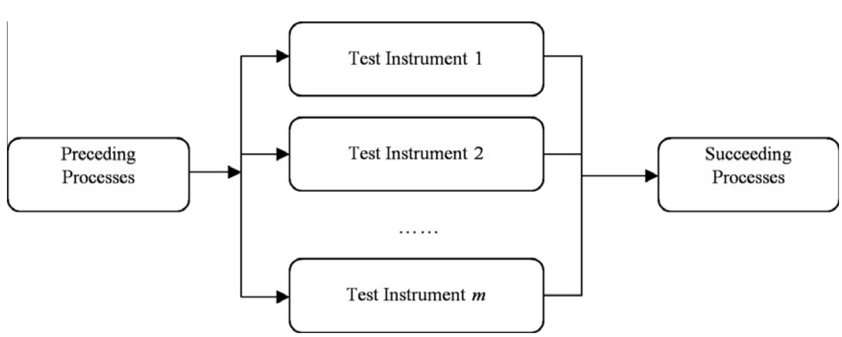

Fig. 1. A multisite testing system.