

Stencil Printing Process Modeling and Control Using Statistical Neural Networks

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Abstract—This paper presents a neural network model for the Stencil Printing Process (SPP) in Surface Mount Technology (SMT) manufacturing of Printed Circuit Boards (PCB). A practical model description that decomposes the overall steady-state process in independently modeled subspaces is provided. The neural network model can be updated in real-time procuring a method to control the process by dynamically searching the optimal set point of the control variables. The optimization is performed by minimizing the weighted mean squared error with respect to the desired solder brick height or volume; furthermore, in the case when multiple solutions exist, the set point that yields the lowest variance is used. The process simulator is mainly suitable for off-line testing and debugging of more complex closed-loop control algorithms for the SPP optimization providing a common and realistic framework for algorithm performance evaluation. An important consideration in this paper is based on the fact that the estimation of the sampled moments of the probability distributions is made using a statistically significant number of data samples from each board, for each component type, for each printing direction, and for each pad orientation.

Index Terms—Stencil printing process model, statistical neural networks, surface mount technology, closed loop control.

I. INTRODUCTION

THE main limitation in the optimization of the SPP is the elevated evaluation cost of the system output function. In order to obtain a single sample output value of the process an individual PCB has to be printed and inspected. Thence, the necessity of finding a method for economically and adequately simulate and study the SPP is very compelling.

Currently, there are no comprehensive practical models for the SPP; however, interesting approaches towards the process understanding include the works by [1–12]. For example, Li and Mahajan [1] studied the effects of PCB design in the SMT manufacturing yield by identifying critical parameters through the use of Analysis of Variance (ANOVA) and using statistical regression and neural networks models for assembly yield prediction. Later, Mahajan [2] introduced a statistical Design Of Experiment (DOE)-based neural network model. This model is based on a Taguchi L27 orthogonal array that is used to statically optimize equipment settings in order to minimize solder paste height variation; in the same study techniques for transferring Artificial Neural Network (ANN) process models between different stencil printers are proposed. Posteriorly, the same author [3] developed the concepts of

physical-neural network models and models transfer, where he demonstrated that they are appropriate in the procurement of low complexity accurate ANN models. The same paper also provides additional developments in novel process control strategies using statistical ANN.

A knowledge-based approach to SPP controller design was developed by Barajas *et al.* [4] by using a combination of neural networks and fuzzy logic. The neural networks were used to determine the membership functions for a fuzzy logic controller and to simulate the process for control signal verification. The fuzzy logic controller was designed in such a way that heuristic knowledge acquired from machine operators was incorporated in the control signal generation. The same authors also presented in [5] a hybrid closed-loop control for the SPP where the optimization objective was to maintain constant the solder-paste-volume deposition while minimizing the response time. The merit of this control is that it minimizes the variance and the steady state error of the weighted sample mean versus the desired height. It also considers print direction and different component types independently. A generalization of this previous work is also presented by Barajas *et al.* in [6]; this control scheme is based on a weak-search algorithm that can be applied in the presence of large amounts of noise and when minimal information is known about the process. The controller employs an affine estimator implemented with a modified version of a constrained conjugated gradient method transitioned into a windowed smoothed block-form of the least-squares algorithm [13].

Recently, Coit *et al.* [7] designed a set of hierarchically connected neural networks. The networks were used to predict thermal behavior of PCBs utilizing board design parameters and process settings. Ultimately, such predictions were used to estimate the quality of solder connections. In addition, Ho and Xie [8] showed that ANN Modeling with confidence bounds is an attractive methodology that complements standard SPC techniques for online process optimization; they used a multilayer feed-forward ANN for SPP performance monitoring. In a closely related paradigm, Morad *et al.* [9] proposed the utilization of a genetic algorithm for process optimization of an ANN process model; the random search algorithms presented were suitable to be used with different optimization criteria of the process capability index.

Other related approaches to the implementation of SPP practical models include the work by Ekere *et al.* [10], where a process modeling map with six main subprocesses for the SPP is presented. These subprocesses are depicted in Figure 1. Such a study shows that the solder paste physical

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