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Using GA-SVM for defect inspection of flip chips based on vibration signals

Ke Li[a], Lingyu Wang[b], JingJing Wu[a], Qiuju Zhang[a], Guanglan Liao[c], Lei Su[a,*]

[a] Jiangsu Key Laboratory of Advanced Food Manufacturing Equipment & Technology, Jiangnan University, Wuxi 214122, China
[b] School of Mechanical Engineering, Zhejiang University, Hangzhou 310027, China
[c] School of Mechanical Science and Technology, Huazhong University of Science and Technology, Wuhan 430074, China

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A B S T R A C T

Flip chip technology has been widely used in IC packaging, and the combination of flip chip technology and solder joint interconnection technology has been utilized in the manufacturing of electronic devices universally. As the development of flip chip towards high density and ultra-fine pitch, the inspection of flip chips is confronted with great challenges. In this paper, we developed an intelligent system used for the detection of flip chips based on vibration. Thirty-four features including 18 time domain features and 16 frequency domain features were extracted from the raw vibration data. The support vector machine was employed to implement the recognition and classification of flip chips. In order to improve the classification accuracy of SVM, cross validation (CV) and genetic algorithm (GA) were utilized to optimize the parameters of SVM respectively. SVM, CV-SVM and GA-SVM were applied to classification separately and the results were obtained. By comparison, GA-SVM can recognize and classify the flip chips rapidly with high accuracy. Thus, GA-SVM is effective for the defect inspection of flip chips.

1. Introduction

In the early 1960s, flip chip technology was originated by IBM. Combined with solder joint interconnection technology, flip chip has been widely applied to the manufacturing of electronic devices. The bare die is turned over and the solder joints are put in order between the chip and substrate to guarantee the thermal conduction and electronic connection. Due to the faults occurring frequently such as fatigue failures and manufacturing defects of flip chips, nondestructive inspection of flip chips is significantly imperative [1,2]. As the development of flip chip towards high density and ultra-fine pitch, some new requirements of packaging materials have appeared, such as lead free and low K, which bring great challenges to the nondestructive inspection of solder joints beneath chips [3–5]. Therefore, the technologies of electronic testing, infrared thermography, X-ray inspection and acoustic microscopy imaging are introduced for the detection of flip chips.

Electronic testing is utilized to detect the solder joints according to the change of resistance [6]. The flip chip is fixed on the pre-designed test board, and a probe contacted with the pre-designed board to put through small current is used for solder joint inspection. The pre-designed board is complex and each kind of flip chips need a board, which brings high expenditure and time consumption. Besides, any mechanical contact may lead to defective solder joints misrecognition [7]. According to the temperature change of the flip chip surface, infrared imaging technology has been applied to solder joint inspection [8]. Lu [9] realized the inspection of flip chips with missing solder joints in terms of the pulsed phase thermography. However, as the solder joint size decreases, the infrared device will be limited by the infrared wavelength. X-ray techniques were also applied to flip chip defect inspection, which contain X-ray photography and tomography. X-ray photography is an effective method on the inspection of solder joint voids and bridge connections, and a fuzzy rule-based system was proposed to recognize the defective solder joints. However, X-ray photography is difficult to detect the tiny cracks and laminations [10,11]. X-ray tomography can inspect defects in vertical direction, but it is not suitable to be applied to on-line detection for the long time-consuming and harmful radiation.

Acoustic microscopy imaging (AMI) is widely utilized for flip chip detection and scanning acoustic microscope has been applied to manufacturing industry. Ultrasound is utilized to scan the sample interface and the internal conditions of the component are detected based on reflected waves [12]. The reflected wave shows the weak bonding joints and voids clearly [13–15]. When there are defects appearing in the periphery of flip chips, the inspection accuracy will be impacted by marginal effects. Semmens used high frequency ultrasound to detect flip chip faults and obtained the internal conditions of the component by analyzing the reflected wave [16]. Zhang [17] improved scanning microscopy and evaluated microelectronic packages by means of sparse

* Corresponding author.
E-mail address: lei_su2015@jiangnan.edu.cn (L. Su).

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representation. Neural network combined with cross-correlation method was employed to detect the defects in flip chip solder joints. Sebastian Brand introduced wavelet and pulse separation analysis to the ultrasonic inspection of solder joints [18]. High frequency ultrasonic scanning microscopy is very efficient for flip chip inspection, while the signal attenuation and diffraction between solder joints and laminated substrates are the major drawbacks, which influence the application for flip chips bonding to the laminated substrates. Recently, an inspection method for flip chips based on vibration analysis was applied extensively, which can detect the chips rapidly without destruction [19–21]. Laser ultrasonic inspection system was developed for flip chip inspection [22,23], and finite element analysis, correlation coefficient, error ratio and modal analysis were also introduced to diagnose the defects.

In this paper, we developed an intelligent device used for the detection of flip chips. The device contains an ultrasonic transducer, a laser scanning vibrometer and a set of vibration analysis system. The ultrasonic transducer transmits ultrasounds to excite the flip chip, and the micro displacements of the chips are gauged by the laser scanning vibrometer. The relevant data acquired by the laser scanning vibrometer is processed by the vibration analysis system. We inspected good chips and chips with missing joints, and 34 features were extracted, including 18 time domain features and 16 frequency domain features. The support vector machine (SVM) was introduced for recognition and classification. For the improvement of the recognition accuracy, cross validation (CV) and genetic algorithm (GA) were employed to optimize the critical parameters of SVM.

The rest of the paper is organized as follows. Section 2 introduces the theoretical basis of the proposed method. Section 3 states the experimental investigation. In Section 4, we demonstrate the features extracted for recognition. We analyze and discuss the classification results in Section 5. The conclusion is depicted in Section 6.

2. Theoretical basis

2.1. Principle of support vector machine

Support vector machine (SVM) is widely used in pattern classification and nonlinear regression. The main idea of SVM is to establish a classification hyperplane serving as the decision surface, which maximizes the distance of the separation edge between the positive cases and the negative cases [24]. SVM is based on the theory of statistical learning and approximately fulfils the minimization of structure risks. The geometric margin can be defined as follows:

$$y_i(\mathbf{w}^T \bullet x_i + b) \geq 1,\ i = 1,\ \dots, m \tag{1}$$

where x is the input set and y is the output set. w represents the connection weights and b refers to the offset. $w \cdot x + b = 0$ is the optimal hyperplane, which maximizes the distance between $w \cdot x + b = 1$ and $w \cdot x + b = -1$, and the margin is $2/\|w\|^2$. In order to maximize the classification interval, $\|w\|$ should be small enough under certain restrictions. Thus, the problem can be regard as follows:

$$\min \frac{1}{2}\|w\|^2 \tag{2}$$

$$s.\ t.\ y_i(\mathbf{w}^T \bullet x_i + b) \geq 1,\ i = 1,\ \dots, m \tag{3}$$

In order to simplify the operation furtherly, the generalized optimal classification surface problem is equivalent to the following functions:

$$\min \frac{1}{2}\|w\|^2 + \frac{c}{m}\sum_{i=1}^{m} \xi_i \tag{4}$$

$$s.\ t.\ y_i(\mathbf{w}^t + x_i + b) + \xi_i \geq 1,\ \xi_i \geq 0,\ i = 1,\ \dots, m \tag{5}$$

where c is the penalty parameter used to reduce the impact of the individuals dissatisfying the constraints. The decision function can be expressed as:

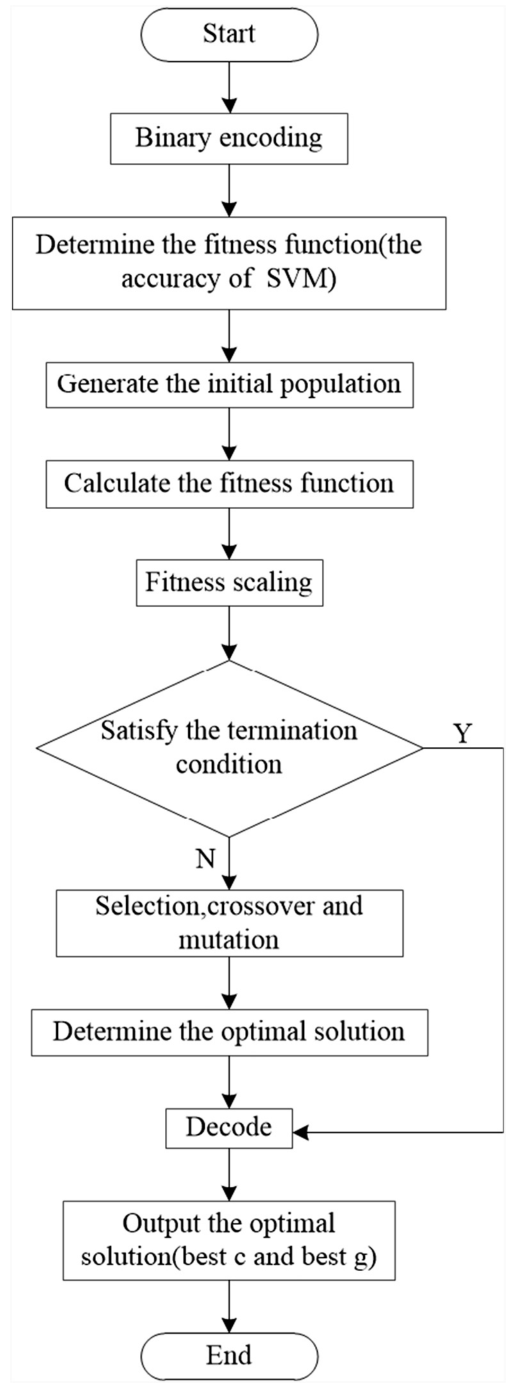

Fig. 1. The procedure of SVM parameters optimized by GA.

$$f(x) = \text{sign}(w \bullet x + b) = \text{sign}\left(\sum_{i=1}^{m} y_i \alpha_i k(x_i, x_j) + b\right) \tag{6}$$

The kernel function contains polynomial, sigmoid kernels and radial basis function, so the kernel parameter need to be optimized to maximize the accuracy of classification. In this research, we selected the radial basis function, which is benefit to express the complex nonlinear relationship between input and output data.

2.2. Parameters optimization of SVM based on cross validation

When SVM is used for classification, some parameters need to be adjusted to attain satisfactory classification result. The penalty parameter c and the kernel parameter g are most important, and cross