Computers and Mathematics with Applications 61 (2011) 2132–2137

Contents lists available at ScienceDirect

Computers and Mathematics with Applications

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

A method of image preprocessing based on nonlinear diffusion and information extraction

Ping Zhong *, Shile Wang, Ye Jin, Xinxing Tu, Nian Luo

College of Science, Donghua University, Shanghai 201620, PR China

ARTICLE INFO

Keywords:
Shadow moiré interferometry
Nonlinear diffusion equation
Fringe thinning
Gradient leading algorithm
Moiré fringe extraction

ABSTRACT

Thermally induced stresses play a very important role in controlling the structural reliability of microchip packages. In order to evaluate the magnitude of the warpage of measured objects caused by such stresses, the shadow moiré technique was suggested, where how the moiré fringes are extracted is the key feature. In this work, an improved filtering algorithm based on a nonlinear diffusion equation is developed and a medial axis transformation and pruning algorithm are applied to extract the skeleton of the moiré fringe. In order to remove the forficate fringe and isolated noise fringe, a main fringe extraction algorithm is then used, and this is discussed in detail. According to the moiré fringe information extracted from the shadow moiré pattern, the three-dimensional image which indicates warpage of the measured object's surface is reconstructed. This demonstrates that the measuring accuracy can be improved up to 2.0 μm by using a grating of 100 lines per inch.

1. Introduction

Thermally induced deformation is one of important aspects in controlling the structural reliability of advanced electronic packages [1,2]. The warpage induced by the mismatch in coefficient of thermal expansion between the module and substrate may cause serious reliability problems, such as severe solder bump fatigue failure, interfacial cracking, etc. [3,4]. The warpage can be measured by different methods, among which the shadow moiré method is considered to be a particularly accurate, real-time, non-contact method with high resolution [5]. Unfortunately, it is difficult to extract effective moiré fringes because of the noise of the interference pattern image [6]. In this paper, we mainly concentrate on algorithm developments for accurately extracting effective shadow moiré fringes by a digital image processing technique.

2. Shadow moiré interferometry

The moiré image obtained in our work is based on the shadow moiré technique [7]. Fig. 1 shows the shadow moiré setup, in which one of the two periodic images comes from a glass grating, and the other is the shadow of the grating lines on a surface being measured. The glass grating is a duplicate of a precision master grating, and is used as the reference. Small variations from the reference grating are magnified by moiré fringes, from which the surface topology can be measured. In practical measurements, the specimen is placed under the reference grating as shown in Fig. 1, and a beam of white light is projected at the angle of 45° through the grating. When the surface of the specimen is curved or warped, moiré fringes are

* Corresponding author. Tel.: +86 02113761336705.
E-mail address: pzhong937@dhu.edu.cn (P. Zhong).

0898-1221/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.camwa.2010.08.096

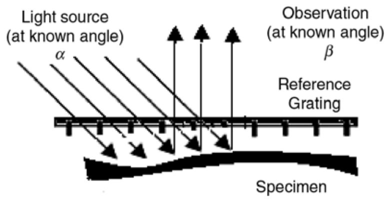

Fig. 1. The principle of the shadow moiré technique.

produced as a result of the geometric pattern created from the interference between the reference grating and the shadow grating. The resulting moiré pattern can be used to characterize the degree of warping of the tested specimen through Eq. (1):

$$W = p/(\tan\alpha + \tan\beta) \tag{1}$$

where W is warpage between adjacent fringes, P is the grating pitch, α is the light angle and β is the observation angle.

3. Preprocessing of the moiré pattern

In the moiré fringe image obtained, it is difficult to extract effective moiré fringe information due to the noises from sensors and the ambient temperature. In order to reduce noises through image preprocessing, many algorithms have been developed, with the balance between the image fuzziness and retaining detail (edge protection) proving a thorny problem. Taking the common template filtering for example, if a large size template is applied, the noise can be greatly reduced but a boundary blurring effect would be in evidence. Conversely, the usage of a small size template may have a small edge blurring effect but the noise reduction is weak. Therefore, with preprocessing algorithms it is normally difficult to satisfy the image filtering requirements. A moiré fringe image comes from the deformation of the object surface and the moiré fringe texture is crowded, which results in difficulty for gaining clear images by using general filtering algorithms. In this paper, a strategy of adopting a partial differential equation model in the image filtering algorithm is proposed. Experimental results show that noise can be effectively reduced by applying this strategy.

3.1. The classical partial differential equation algorithm

One classical partial differential equation algorithm model used for auto-adapted smoothing is the PM (Perona–Malik) aeolotropism diffusion model [8], which mainly introduces the step of marginal testing in the filtering process. By this method, the filter can eliminate noise from an image and reserve the edge information. However, there are still two problems with this model that need to be addressed. Firstly, in the noise-mixed signals, noises can easily cause a crest value of the gradient, which leads to infinite vibration, theoretically. This vibration is difficult to restrain and consequently almost all of the noises cannot be filtered out. Secondly, the equation used in this model is an ill-conditioned equation and the uniqueness of the solution is difficult to guarantee. For this PM model, there are some improved algorithms [9,10].

In this paper, a nonlinear parabola-like partial differential equation algorithm is introduced for image preprocessing. This equation is expressed as

$$\partial u(x, y, t)/\partial t = g(|G * Du|)|Du|\mathrm{div}(Du/|Du|), \quad u(x, y, 0) = u_0(x, y). \tag{2}$$

Alvarez et al. [11] considered that when the change of the greyscale in the neighborhood of (x, y) was small, it still diffused along the direction orthogonal to the gradient, which caused low diffusion efficiency. In this situation, the neighborhood of (x, y) does not contain important image information, so we can adopt the isotropic heat diffusion equation. Therefore, the following nonlinear diffusion equation is suggested:

$$\partial u(x, y, t)/\partial t = g(|DG_\sigma * u|)[1 - h(|Du|)]\Delta u + h(|Du|)|Du|\mathrm{div}(Du/|Du|), \quad u(x, y, 0) = u_0(x, y) \tag{3}$$

where $h(s)$ is a smooth non-decreasing function; when $s > AE$, $h(s) = 1$. The model reduces to the diffusion equation. The image is operated along the orthogonal gradient direction. When $s < AE$, $h(s) = 0$, the model becomes the heat diffusion equation. It has the same diffusion velocity in each direction, namely the image and Gaussian filter are convoluted, which is useful for removing isolated noise.

The experimental results suggest that the model retains almost all effective information on the boundary [12]. But the model is confined to relatively straight boundaries with small curvature. For boundary lines with great curvature, the filter effect is weak, like that for the vertex. In the filter process, the diffusion rate depends only on the local grey gradient, that is to say, it operates the image along the tangential direction regardless of the changing grey gradient in the tangential direction. Thus, with increase of the number of iterations, the pixel with large value of the second derivative becomes fuzzier, gradually, until it is lost.

The grain direction of the moiré image is usually a closed or half-closed curve, so the most important feature of these images can be described as a curvature, which is proportional to the second derivative. When $h(s) = 1$, the degenerate equation of Alvarez's model diffuses along the tangential direction (orthogonal to the gradient direction). For those edge