Computer-Aided Inspection of Optical Components
Using Computer Vision Technologies

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Abstract – Light-emitting diode (LED) lenses are one kind of common optical components. The LED lens with uneven surface is difficult to detect surface defects. This research proposes a wavelet packet transformation based partial least square approach to detect surface defects of optical components with uneven surfaces. Three procedures are developed to do the process of defect detection. Firstly, a spatial domain image is converted to wavelet pack domain and the wavelet features of the sub-band images are extracted. Secondly, the partial least square method is used to multivariate transform with wavelet features to obtain latent images. Thirdly, the latent images are fitted by a regression model to get the residual image where the surface defects have been separated. Experimental results show that performance of the wavelet pack based approach in the defect detection is effective and efficient.

Keywords: Computer-aided inspection; optical components; uneven surface; wavelet packet transform.

1 Introduction

A light-emitting diode (LED) is a semiconductor device that emits visible light when an electric current passes through the semiconductor chip. Typical applications of LED components include indicator lights, LCD panel backlighting, fiber optic data transmission, etc. The functions of LED lenses include focusing, beauty, and protection to avoid the waste of light and light pollution. Optical lenses are transparent components made from optical materials and curved to converge or diverge transmitted rays from an object. Lenses are typically made of glass or transparent plastic. Optical lenses are widely used in cell phone, notebooks, automotive, digital camera, LED etc.

Appearance differences among the clear lenses, diffused lenses, and textured lenses of LEDs are various designs for providing the lighting energy distribution in the areas of interest and reducing the uncomfortable glare effect for the general illumination applications. Figure 1 shows a LED lens and a LED product with uneven surfaces. Visual defects on the uneven surfaces are difficult to be inspected out for professional inspectors due to repetitive texture patterns on lens surfaces.

The most common detection method for visual defects on LED lenses is human visual inspection. Figure 2 shows a defect-free LED image and a defective image with surface defects. Human visual inspection is tedious, time-consuming and highly dependent on the inspectors’ experiences. Erroneous judgments are easily made because of inspectors’ subjectivity and eye fatigues. Difficulties exist in correctly inspecting defects by machine vision systems because when product images are being captured, the area of a small defect could expand, shrink or even disappear due to uneven illumination of the environment, and uneven surfaces of the products, and so on. This study proposes a wavelet packet transformation based partial least square approach to overcome the difficulties of traditional machine vision systems.

Inspection of surface defects has become a critical task for manufacturers who strive to improve product quality and production efficiency [1]. Defect detection techniques, generally classified into the spatial domain and the frequency domain. Latif-Amet et al. [2] presented wavelet theory and co-occurrence matrices for detection of defects encountered in textile images and classify each sub-window as defective or non-defective with a Mahalanobis distance. Cho et al. [3]
applied the adaptive threshold technique and morphology method to detect defects from images of uniform fabrics for developing a real-time vision system.

As to techniques in the frequency domain, Chan and Pang [4] used the Fourier transform to detect fabric defects. Tsai and Hsiao [5] proposed a wavelet transform based approach for inspecting local defects embedded in homogeneous textured surfaces. By properly selecting the smooth sub-image or the combination of detail sub-images for reverse wavelet transform, repetitive texture patterns can be removed and only defects are enhanced. Lin and Ho [6] developed a novel approach that applies discrete cosine transform based enhancement for the detection of pinhole defects on passive component chips.

The discrete wavelet transform permits a time-frequency decomposition of the input signal, but the degree of frequency resolution in the discrete wavelet transform is typically considered too coarse for practical time-frequency analysis [7]. The wavelet packet transform provides a computationally efficient alternative with sufficient frequency resolution. In the wavelet packet transform, the filtering operations are also applied to the wavelet, or detail, coefficients. Lee et al. [8] proposed a feature-based adaptive wavelet packet method to inspect surface defect on cold rolled strips.

Partial least squares technique was initially proposed by Wold [9]. It is a statistical method that bears some relation to principal components analysis and it finds a linear regression model by projecting the predicted variables and the observable variables to a new space [10]. Because both the independent and response data are projected to new spaces, the partial least square method is one of the important multivariable statistical techniques to reduce the dimensionality of the plant data, to find the latent variables from the plant data by capturing the largest variance in the data and achieves the maximum correlation between the predictor variables and response variables [11].

2 Proposed methods

This research proposes a wavelet packet transformation based partial least square approach to detect visual defects of LED lenses on uneven surfaces. A spatial domain image is converted to wavelet packet domain and the wavelet features of the sub-band images are extracted. Then, the proposed partial least square method is applied to multivariate transform with wavelets features to obtain latent images. Finally, the latent images are fitted by a regression model to produce a predicted image to get the residual image where the visual defects have been separated. Therefore, the visual defects on the uneven surfaces of LED lenses can be accurately detected and located by the proposed method.

The inspection task of this paper involves detecting visual defects on uneven surfaces of LED lenses in optical components. Many of these unanticipated defects are extremely small in size and cannot be described by explicit measures, thus making computer-aided defect detection difficult. With good time-frequency discrimination ability, wavelet transforms are now widely used for analysis of various signals in time and frequency domain simultaneously. In the orthogonal wavelet decomposition procedure, the generic step splits the approximation coefficients into two parts. After splitting we obtain a vector of approximation coefficients and a vector of detail coefficients, both at a coarser scale. Then the next step consists of splitting the new approximation coefficient vector; successive details are never reanalyzed. In the corresponding wavelet packet situation, each detail coefficient vector is also decomposed into two parts using the same approach as in approximation vector splitting.

Partial least square is used to find the fundamental relations between two matrices X and Y, i.e. a latent variable approach to modeling the covariance structures in these two spaces. A partial least square model will try to find the multidimensional direction in the X space that explains the maximum multidimensional variance direction in the Y space. The partial least square regression is particularly suited when the matrix of predictors has more variables than observations, and when there is multicollinearity among X values. The partial least square regression generalizes and combines features from principal component analysis and multiple regression. This prediction is achieved by extracting from the predictors a set of orthogonal factors called latent variables. The partial least square regression is particularly useful when we need to predict a set of dependent variables from a large set of independent variables.

Three steps are developed to finish the process of defect detection. Firstly, a spatial domain image is converted to wavelet pack transform domain and the wavelet features of the sub-band images are extracted. Secondly, the proposed partial least square method is applied to multivariate transform and data reduction with wavelets features to obtain latent images. There is as much information in the latent components as that in the original features. Thirdly, the latent images are fitted by a regression model to produce a predicted image and then subtract with the original image to get the residual image where the visual defects have been separated.

Cross-validation method determines the number of latent variables for obtaining better ability of the model fitness. The index of prediction sum of squares (PRESS) is used to evaluate the model fitness. It is expressed as,

\[
PRESS = \sum_{x=0}^{W} \sum_{y=0}^{H} [Y(x,y) - \hat{Y}(x,y)]^2
\]  

(1)
We find the fitted image with 4 latent vectors has a better flaw detection of LED lens. The partial least square model with 4 latent vectors has the lowest PRESS index. Figure 3 demonstrates a defective LED lens image with its three latent images. The latent image of the current iteration is obtained from the residual estimate of the previous latent image.

![Figure 3](image_url)

**Figure 3.** A defective LED lens image with its three latent images.

3 **Experiments and analyses**

In the assessments, the proposed approach is implemented and experiments are conducted to evaluate its performance in detecting visual defects on uneven surfaces of LED lenses. To verify the performance of the proposed method and other approaches, we compare the results of our experiments against those provided by professional inspectors. The performance evaluation indices, \((1-\alpha)\) and \((1-\beta)\), are used to represent correct detection judgments; the higher the two indices, the more accurate the detection results. Statistical type I error \(\alpha\) suggests the probability of producing false alarms, i.e. detecting normal regions as defects. Statistical type II error \(\beta\) implies the probability of producing missing alarms, which fail to alarm real defects. We divide the area of normal region detected as defects by the area of actual normal region to obtain type I error, and the area of undetected defects by the area of actual defects to obtain type II error. The correct classification rate (CR) is defined as:

\[
CR = \frac{(N_{cc} + N_{dd})}{N_{total}} \times 100\% \quad (2)
\]

where \(N_{cc}\) is the pixel number of normal textures detected as normal areas, \(N_{dd}\) is the pixel number of defects detected as defective regions, and \(N_{total}\) is the total pixel number of a testing image.

Figure 4 shows partial results of detecting visual defects by the Otsu method [12], the proposed method, and the professional inspector, individually. The spatial domain technique, the Otsu method, make lots of erroneous judgments (false alarms) on visual defect detection. The frequency domain technique, the proposed method, detect most of the visual blemishes and make less erroneous judgments. Therefore, the frequency domain approach outperforms the spatial domain technique in the visual defect detection of LED lenses with uneven surfaces.

4 **Conclusions**

Machine vision technologies improve productivity and quality control, and provide competitive advantages to industries that employ these techniques. This study proposes a wavelet packet transformation based partial least square approach for the computer-aided inspection of visual defects on uneven surfaces of LED lenses. Real LED lenses are used as testing samples, and large-sample experiments are conducted in a real inspection environment to verify the performance of the proposed method. Experimental results show that the proposed approach achieves a higher probability of correctly discriminating visual defects from normal regions and a lower probability of erroneously detecting normal regions as defects on uneven surfaces of LED lenses. This research contributes a solution to a common visual defect detection problem of LED lenses with uneven surfaces.

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6 **References**


Figure 4. Partial detection results of the Otsu method, proposed methods, and inspector.