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Crack detection in magnetic tile images using nonsubsampled shearlet transform and envelope gray level gradient

Chengli Yang, Peiyong Liu, Guofu Yin*, Ling Wang

School of Manufacturing Science and Engineering, Sichuan University, Chengdu 610065, PR China

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ABSTRACT

A novel algorithm based on nonsubsampled shearlet transform (NSST) and envelope gray level gradient (EGLG) is proposed for detecting low-contrast cracks in variably illuminated magnetic tile images. The algorithm first adopted NSST to decompose the original images into multiple subbands at different directions and scales. Then a novel column filtering based on EGLG was employed to remove the uneven background in the approximation subband, and a shearlet coefficient variance discriminator (SCVD) was used to eliminate interferences of noise and textures in the detail subbands. Finally the cracks were extracted from the reconstructed images. To verify the validity of the proposed algorithm, extensive experiments were conducted in a novel machine vision based system and its comparison with traditional algorithms was given. Experimental results show that this method achieves an accuracy rate of 95.5% in detecting cracks longer than 0.9 mm with an average runtime of 0.576 s, and outperforms traditional methods in terms of accuracy and robustness.

1. Introduction

With the rapid development of automation technology, magnetic tiles are more and more extensively used in permanent magnet motors and play an important role in the performance of relevant products. Limited by the current technology level of powder metallurgy, various defects are inevitably produced in the production process of magnetic tiles, among which crack defect is the most common type and is difficult to be recognized from the inhomogeneous background by human vision. As a consequence, the automation of the surface crack detection process has become an urgent task in magnetic tile industry.

In recent years, machine vision technology has been widely applied in the field of surface defect detection due to the advantages of high efficiency and low cost [1]. Currently, one of the research hotspots in this area is how to distinguish continuous defects with small sizes from stochastic interferences represented by noise and textures [2], which fits well with the task in this work. Notably, researchers have proposed a number of effective solutions for this issue. Zhao et al. [3] proposed a real-time target detection approach in infrared imagery. In the method, saliency extraction and threshold processing were adopted to extract the potential targets map. Then a morphological operation was used for noise suppression. The experimental results prove the approach is robust and efficient for target detection. However it relies on too many parameters and the global threshold is only available for uniform background. In Li et al. [4], a lower envelope Weber contrast (LEWC) recognition algorithm was proposed to detect steel bar surface pit defects. In the method, the lower envelope of column pixels was used to eliminate the effect of high gray level noise, and Weber contrast was employed to ensure that all areas in one image had the same threshold to detect pit defects. The experimental results indicate that their method has a high detection accuracy and is not affected by the size of pit defects. Nevertheless, the operations of ideal low pass filtering and mean value calculation lead to the loss of defect details and the work is incapable of making a quantitative evaluation for defects.

It should also be noted that a series of multi-resolution analysis (MRA) techniques have received increasing attention in image processing over the past few years. Typical examples include wavelet [5], curvelet [6], contourlet [7] and shearlet [8]. Sun et al. [9] presented a novel and fast non-uniform background removal algorithm based on multi-scale wavelet transform (WT). In the method, the pavement image was decomposed by WT and the background was reconstructed using the low-wavenumber components through inverse WT. Then the brightness of image background was corrected and the cracks could be extracted from the uniform image. In Li et al. [10], a new algorithm based on the fast discrete curvelet transform (FDCT) and texture analysis was proposed for detecting crack defects with dark color and low contrast in magnetic tile images. The algorithm first decomposed the original images into multiple subbands at different directions and scales using FDCT. Then textures in each subband were eliminated with the threshold calculated by texture feature measurements. Finally,

* Corresponding author.
E-mail address: gfyin@scu.edu.cn (G. Yin).

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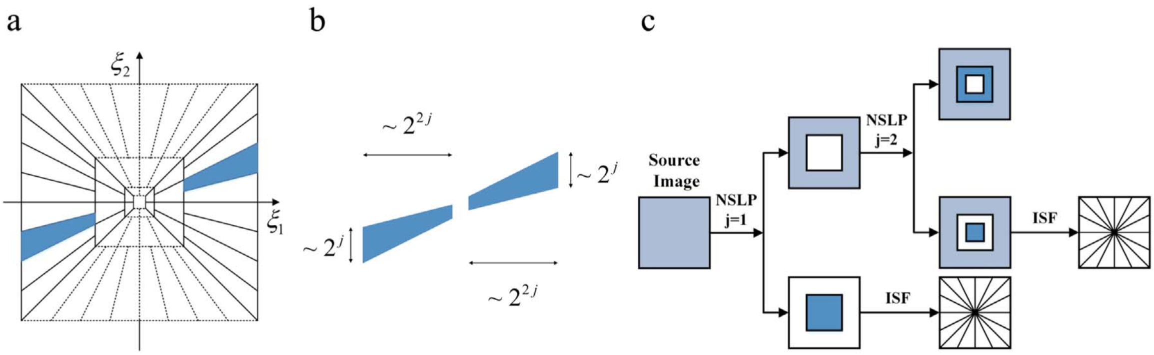

Fig. 1. Frequency support and structure of NSST. (a) The tiling of the frequency plane induced by the shearlets. (b) The frequency support of a shearlet $\psi_{j,l,k}$. (c) Two level multi-scale and multi-directional decompositions of NSST.

the crack contours were extracted from the reconstructed images by employing Canny operator. The method can effectively eliminate the grinding textures, but it requires a strict lighting condition for image acquisition. By combining non-subsampled contourlet transform (NSCT) and mathematical morphologies, Li et al. [11] proposed a novel surface segmentation method. The algorithm decomposed the structured surface into multiple scales using NSCT. Then the coarse scaled edges could be obtained by using mathematical morphology and the fine scaled edges could be extracted by applying an adaptive threshold method. Finally the edges in non-stochastic surfaces were segmented effectively. More recently, Duval-Poo et al. [12] discussed an effective scheme to exploit the shearlet transform (ST) for the estimation of edges, namely the shearlet cascade edge detection (SCED) algorithm. The algorithm estimated the edge energy by reasoning on the behavior of shearlet coefficients at different scales of a given point of the image. Then the functions of non-maxima suppression and threshold were carried out to decide whether an image point is an edge or not. The thorough experimental analysis on benchmark datasets demonstrates the superiority of shearlets over wavelets for edge detection in both quantitative and qualitative evaluations.

In this paper, a novel algorithm based on nonsubsampled shearlet transform (NSST) and envelope gray level gradient (EGLG) is proposed for crack detection in magnetic tile images. By eliminating the subsampling process, NSST becomes the improved version of ST and has better performance in terms of shift-invariance, which means less sensitivity to the image shift [13]. As a result, the Gibbs phenomenon is suppressed effectively and each decomposition subband has the same size with the source image [14], which are extremely critical for our interference elimination operation in Section 3. Compared with other MRA methods mentioned above, NSST not only has the properties of multi-scale, localization and anisotropy, but also exhibits better orientation sensitivity in representing distributed singularities by adopting the shift-invariant shearing filters in the directional decomposition [15], which are perfect for the inspection of edges in piecewise smooth images. Moreover, due to the simple mathematical framework, NSST has relatively low computational complexity. Benefiting from these properties, NSST significantly outperforms other MRA methods, which has also been successfully demonstrated by some excellent papers dealing with issues of image enhancement [16], image fusion [17], noise reduction [18] and feature detection [19]. For the online detection of cracks in magnetic tile images, high detection accuracy and efficiency are demanded simultaneously. From the above analysis, it is clear that NSST is particularly appropriate for this task. Besides, since the magnetic tile images suffer much from uneven illumination, a novel column filtering based on EGLG is carried out to correct the brightness of image background.

The remainder of this paper is organized as follows. Section 2 briefly introduces the characteristics of NSST. Section 3 illustrates the crack detection algorithm in detail. Section 4 presents the experimental results and makes a discussion. Finally, the whole paper is concluded in Section 5.

2. Nonsubsampled shearlet transform

In this section, we briefly review the theory of NSST, which will be used in the subsequent sections. In dimension 2, the affine system with composite dilations is given by [15,20]:

$$\{\psi_{j,l,k}(x) = |\det A|^{j/2}\ \psi(S^l A^j x - k):\ j,\ l \in \mathbb{Z},\ k \in \mathbb{Z}^2\}, \tag{1}$$

where ψ is a collection of basis function and satisfies $\psi \in L^2(\mathbb{R}^2)$. A refers to the anisotropic matrix for multi-scale decomposition, and S denotes the shear matrix for multi-directional decomposition. A and S are 2×2 invertible matrices and $|\det S| = 1$. j, l and k are scale, direction and shift parameter, respectively. For each $a > 0$ and $s \in R$, A and S are defined as follows:

$$A = \begin{pmatrix} a & 0 \\ 0 & \sqrt{a} \end{pmatrix},\ S = \begin{pmatrix} 1 & s \\ 0 & 1 \end{pmatrix}. \tag{2}$$

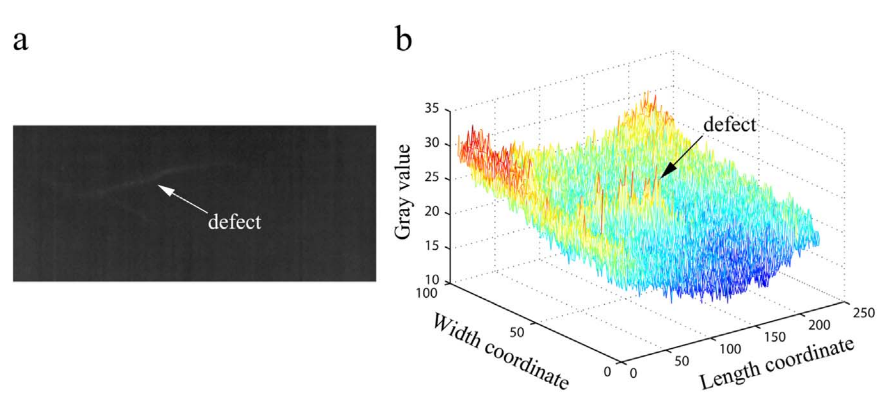

Fig. 2. Original defect image: (a) two-dimensional image and (b) three-dimensional image.