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Research Article

Surface defect detection in tiling Industries using digital image processing methods: Analysis and evaluation

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ABSTRACT

Ceramic and tile industries should indispensably include a grading stage to quantify the quality of products. Actually, human control systems are often used for grading purposes. An automatic grading system is essential to enhance the quality control and marketing of the products. Since there generally exist six different types of defects originating from various stages of tile manufacturing lines with distinct textures and morphologies, many image processing techniques have been proposed for defect detection. In this paper, a survey has been made on the pattern recognition and image processing algorithms which have been used to detect surface defects. Each method appears to be limited for detecting some subgroup of defects. The detection techniques may be divided into three main groups: statistical pattern recognition, feature vector extraction and texture/image classification. The methods such as wavelet transform, filtering, morphology and contourlet transform are more effective for pre-processing tasks. Others including statistical methods, neural networks and model-based algorithms can be applied to extract the surface defects. Although, statistical methods are often appropriate for identification of large defects such as Spots, but techniques such as wavelet processing provide an acceptable response for detection of small defects such as Pinhole. A thorough survey is made in this paper on the existing algorithms in each subgroup. Also, the evaluation parameters are discussed including supervised and unsupervised parameters. Using various performance parameters, different defect detection algorithms are compared and evaluated.

1. Introduction

Nowadays, ceramic and tile industry represents one of the most dynamic industries, including lots of innovations in various stages of production and automation. However, human vision control is still used for detection of defective products and grading and automatic grading is not yet well established [1]. Grading is implicitly related to the whole fabrication line because various surface defects such as color, image pattern, crack or scratch, arc, and bumps on the ceramic or tile originate from different stages [1]. The main challenge of automatic grading is in the image processing algorithms required for defect detection. Different challenges of grading are namely various kinds of color, different kinds of texture design, real-time processing requirement and the vast types of defects [1]. Current grading is usually done in three stages: first, tile arc is measured by a linear planer; then, size difference compared to ideal size is measured by a stacker; finally, surface defects are identified by human vision and registered on the product surface with fluorescent markers. This traditional and non-automatic grading process suffers from problems such as poor performance, non-repeatable procedure, high cost, and low speed. Industrial and unhealthy environment of product line for humanitarian personnel is another negative factor of manual grading.

The automatic grading system would result in better performance, lower cost, and uniformity in each category of products. The current increasing demand of tile and ceramic validates the market need of automatic grading for higher production speeds [2]. In modern production lines, tiles are actually classified into five grades based on the three above mentioned evaluation criteria, in which level five is considered as losses [3].

Up to now, various processing algorithms have been proposed for intelligent grading. These methods can be divided into four main categories according to the defect detection mechanism: filtering methods, structural techniques, statistical methods, and model-based techniques (Table 1). Filtering methods usually use mathematical translation and filters or pattern recognition methods for defect detection. The structural approaches consist of conventional morphological image processing and edge detection algorithms. Model-based approaches include common image

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Table 1
Different approaches of defect detection.

Approach	Processing algorithm	References
Filtering methods	Wavelet transform	[12–18]
	Countorlet transform	[19–21]
	Genetic algorithm	[22–26]
	ICA algorithm	[27–30]
	Neural networks	[32–35]
	Gabor filter	[36–38]
Structural algorithms	Morphology	[39–47]
	Edge detection	[7,11,48–51]
Model based techniques	Hidden Markov model	[59–61]
	Autoregressive model	[62–65]
Statistical methods	Histogram curve	[66,67]
	Co-occurrence matrix	[68–76]
	Weibull distribution	[77–82]
	Autocorrelation	[83,84]

processing models like the Auto-Regressive (AR) and Hidden Markov Models (HMM). In the statistical approaches, luminance histogram is generally used for defect detection. Statistical methods are characterized by simplicity as well as low complexity [4].

Because of various chemical and mechanical processes in the ceramic tile production line, diverse types of surface defects appear on the final product. The defects generally have different visual patterns which are sometimes contradictory. Therefore, the desired grading system should include a variety of image processing algorithms to cover different types of surface faults or defects.

In this paper, the proposed algorithms for grading system in ceramic and tile production line are discussed and evaluated in terms of output quality and computational complexity. In Section 2, different types of surface defects appearing in the fabrication lines of ceramic and tiles are studied. In Section 3, different defect detection algorithms are discussed. Then, Section 4 deals with the evaluation parameters. Firstly, available measures described for evaluating defect detection algorithms are presented. Using quality parameters, proposed techniques are compared. Finally, the discussions are concluded in Section 5.

2. Surface defects of ceramic and tiling

Ceramic and tile products pass various chemical and mechanical stages through the production line. Production of ceramic tiles comprises eight main stages: forming, drying, glazing, baking, grading, and sorting [92] as shown in Fig. 1. Glazing defects occur in glazing and printing stages. Defects that are associated with breaking and cracks happen in the forming and baking stages. In contrast, edge defects are caused more by the transmission process from glazing lines to kiln. Also, the Pinhole defect occurs typically in kiln [3].

Accordingly, surface defects can be divided into six categories with the following characteristics (Fig. 2) [5].

- Pinhole
  Pinhole is a quality fault appearing as small holes on the product surface. Pinhole sizes are typically less than one millimeter. Also, the holes appear with a lumber and depression. This fault typically occurs during baking.
- Eclipse glaze
  This problem originates from accumulation of a part of glaze over a corner or part of the tile. Accumulation of glaze is usually on a few millimeters with significant expansion in the region of defect. This defect appears in the glazing stage by creeping and ringing of the glaze [5].
- Crack
  The most common defect is the crack which occurs because of fast baking procedure with rapid increase or decrease in temperature. Cracks at the edges of the tile are mostly caused due to increasing temperature. Cracks due to decreasing temperature are also called air cracks or cold cracks and often occur because of fast baking procedure in the kiln [6].
- Blob
  Some patches like spot drops of water may exist on the tile surface, and are called blob defects. It occurs if humidity is not adjusted or a low sleep time is included before entering into the kiln.
- Scratch
  This failure occurs because of dragged color printing in some directions. This defect is often created during the transmission of products from glazing line to the kiln.
- Edge
  Edge defects occur most commonly in the kiln but they may be generated from other manufacturing stages [7–9].

3. Algorithms of defect detection for ceramic and tile products

For the detection of surface defects, it is required to analyze the whole product surface. So, an image with high resolution should be firstly captured. The system must have appropriate lighting to obtain a suitable surface picture. According to Table 1, the defect detection algorithms may be classified into four principal groups. Here, the main algorithms of each group are discussed.

3.1. Filtering approaches

In the filtering approaches, mathematical transformations and filters are generally used. In this regard, both linear and nonlinear transforms may be used. The most important algorithms include the Wavelet and Counterlet transform, Independent Component Analysis (ICA) analysis, Gabor filtering and artificial neural networks which are discussed below.

3.1.1. Wavelet transform

According to the nature of multi-resolution analysis, wavelet transform has been extended for many processing applications and is sometimes known as the most powerful tool [10,11]. In wavelet transform, two low-pass h and high-pass g filters called father and mother functions, respectively, are used in a filter bank way (Fig. 3) [12]. In Fig. 3, the input is an $n \times m$ image and there are also four outputs of LL, LH, HL and HH with size $(n/2) \times (m/2)$. At each stage, the input image is divided into four sub-images.

Wavelet transform has been used for pre-processing and texture feature extraction [13]. In 2001, Kumar and Pang proposed a method of defect detection based on wavelet packet. There, the wavelet packet coefficients from a set of dominant frequency channels containing significant information are used for the characterization of textured images. This method is useful in very soft texture changes [14]. In 2005, Yang et al. applied a similar method to inspect the fabrics in textile factories for defect classification using discriminative wavelet frames. For a better description of the latent structure of the textile image, adaptive wavelet frames for textile would be preferred rather than standard ones. The challenge in this method is how to select the wavelet. Also, the training stage is so dependent on the number of data points [15].