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Research article

Real-time biscuit tile image segmentation method based on edge detection

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ABSTRACT

In this paper we propose a novel real-time Biscuit Tile Segmentation (BTS) method for images from ceramic tile production line. BTS method is based on signal change detection and contour tracing with a main goal of separating tile pixels from background in images captured on the production line. Usually, human operators are visually inspecting and classifying produced ceramic tiles. Computer vision and image processing techniques can automate visual inspection process if they fulfill real-time requirements. Important step in this process is a real-time tile pixels segmentation. BTS method is implemented for parallel execution on a GPU device to satisfy the real-time constraints of tile production line. BTS method outperforms 2D threshold-based methods, 1D edge detection methods and contour-based methods. Proposed BTS method is in use in the biscuit tile production line.

1. Introduction

Modern ceramic tiles production is a highly automated process with sophisticated technologies that meet the requirements on environment protection and energy savings [1,2]. Exceptions are the visual inspection and classification of the final product. Inspection is based on detecting anomalies which are present on tile's surface, texture and edges. Usually, human operators are grading tiles quality (first, second and third class). These operators inspect the final product (ceramic tile) and are often affected by problems like eye fatigue, lack of attention, sickness and slow response [3,4].

Ceramic tile is created after three different tile production stages on a production line. In the first stage a green tile is created from material mixture using large press machines. In the second production stage the biscuit tile is created by adding glazing to the top side of the green tile. A biscuit tile is fragile since it is not fired. It may be easily damaged during the fabrication process and may leave some material fragments on conveyor belts. In the third production stage a ceramic tile is created by firing the biscuit tile [5]. Visual inspection of a tile is possible after each of the three production stages. Usually, visual inspection is done at the end of the tile production line (ceramic tile). In the case when defects are detected, defective tiles are proceeded to the grinding process and are returned to the material mixture at the beginning of the production line. In this case energy is spent on glazing, firing and grinding. Tiles can be inspected in the green tile stage where edge and corner defects may be detected. Also, tiles can be inspected at the biscuit tile stage where edge, corner and surface defects may be detected. In these cases, no energy is spent on firing defective tiles and they are immediately returned to the material mixture without grinding. Since green tiles can have only edge and corner defects (not surface), from economical aspect it is more cost effective to visually inspect biscuit tiles. However, placing more visual inspection devices along production line lowers the costs and decreases the number of defective tiles that reach a human inspection at the end of the production line.

Biscuit tile image segmentation consists of several stages. In the first stage, a tile passes through tile guides to align tile's orientation with conveyor belts, cf. Fig. 1. After alignment, tile's orientation is ranging from $-2.1°$ to $2.1°$ relative to conveyor belts. Additional alignment is possible with another pair of tile guides. The second stage consists of the image acquisition with an area-scan camera [6]. For this stage a uniform light source with no flickering and a hous-

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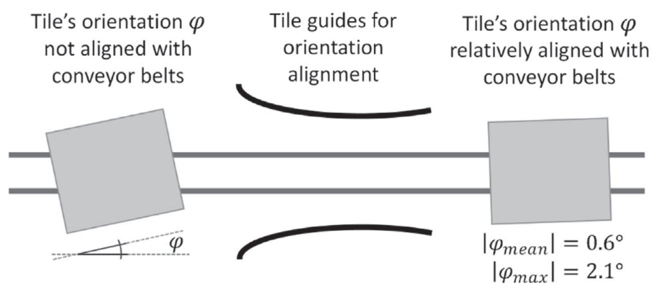

Fig. 1. Ceramic tile orientation alignment.

ing that prevents dust and undesired particles is used. The captured image consists of the tile's surface (object) and the background which is a black image with two conveyor belts covered with dust and fragments from the tile body. In the third stage the image processing is conducted, where the tile's contour and surface is extracted to detect edge, corner and surface defects. In the case when tile edge and corner defects are not found, the tile's surface is inspected. Image segmentation methods are applied to segment the contour and the surface of the tile to create a rectangular pixel matrix, which has only tile's surface pixels and no background pixels, cf. Fig. 2. With a rectangular tile's surface pixel matrix it is possible to efficiently apply surface defects detection algorithms [7–9]. When a fragile biscuit tile moves along the production line, it leaves material fragments on conveyor belts. These fragments usually change the black colour of conveyor belts to the colour which is similar to the colour of a biscuit tile. This is an additional problem for contour and surface extraction methods. Finally, biscuit tiles are classified in two classes, a *good class* with no defects and a *bad class* with defects. Tiles from the *bad class* are proceeded to the material mixture in the beginning of the tile production line.

Defects which are visible with human eyes from one meter distance must be detected [10]. In this paper, resolution of 4px/mm is considered. Example images of biscuit tiles are depicted in Fig. 3.

Biscuit tile visual inspection system must satisfy real-time constraint, which is conditioned by the speed of continuously moving tiles on a single production line. Usually, several production lines are used in parallel. Total available time t_A for the complete image processing procedure increases with increasing dimensions of a tile due to the production process, cf. Table 1. Total available time is $t_A \geq t_P + t_S + t_D$, where t_P is the image preprocessing time for image capture and geometric distortion correction, t_S is the image segmentation time for segmenting tile pixels from the background and t_D is the time for defects detection, i.e. *edge and corner defects detection* and *surface defects detection*. Tile image segmentation is the most important procedure for the classification accuracy. On one hand, small misclassification error in tile image segmentation may cause false detection of edge and corner defects, i.e. tile misclassification. On the other hand, most of the available time t_A is spent on defects detection t_D and therefore the time for the image segmentation t_S must be as small as the image preprocessing time t_P, which is 100 ms, cf. Table 1.

1.1. Related work

Generally, thresholding is commonly used for the foreground/background separation in image binarization. Since images depict different scenes, more or less complex, there is no one satisfactory algorithm used for a general thresholding method [11]. In most cases, thresholding does not yield perfect results and further processing is required [12]. Together with surrounding background, images of plain one-coloured, pseudo-random and random textured biscuit tiles have a distinct bimodal histogram. Otsu thresholding (OTSU) method is described in literature as optimal for thresholding large objects (biscuit tile) from the background when histogram has bimodal shape [13–16]. Minimum Error Thresholding (MET) method [17] is also used on images with bimodal histogram. MET gives better results than OTSU for images where the object is much smaller (1:100 pixel ratio) than the background. Authors in Ref. [18] implemented the Minimum Cross-Entropy Thresholding (MCET) method [19] to separate the ceramic tile from the background. In order to find a threshold value, cluster based methods can be applied on the image histogram [20–22]. Authors in Refs. [23,24] applied histogram subtraction methods for ceramic tile image thresholding.

Camera-based methods are a common approach for a ceramic tile anomalies detection. On the other side, depth-image-based methods are recently applied on ceramic tiles for cracks detection. Authors in Ref. [25] are using microwave radar imaging, while ultrasound technology is used in Ref. [26]. Using depth images it is possible to detect anomalies beyond its surface, giving an insight to a tile's density and homogeneity. Depth-image-based methods enable more efficient inspection in the case when a tile has a complex texture on its surface. Due to technological constraints, these methods enable only a rough detection of large anomalies on a tile's edge and surface.

Statistical methods based on random fields, e.g. Hidden Markov Random Fields (HMRF) [27,28] and Conditional Random Fields [29]. Main disadvantage of these methods is their too long execution time for real-time applications (half a minute or more for 600 × 300 image). Active Contours Without Edges (ACWE) method detect

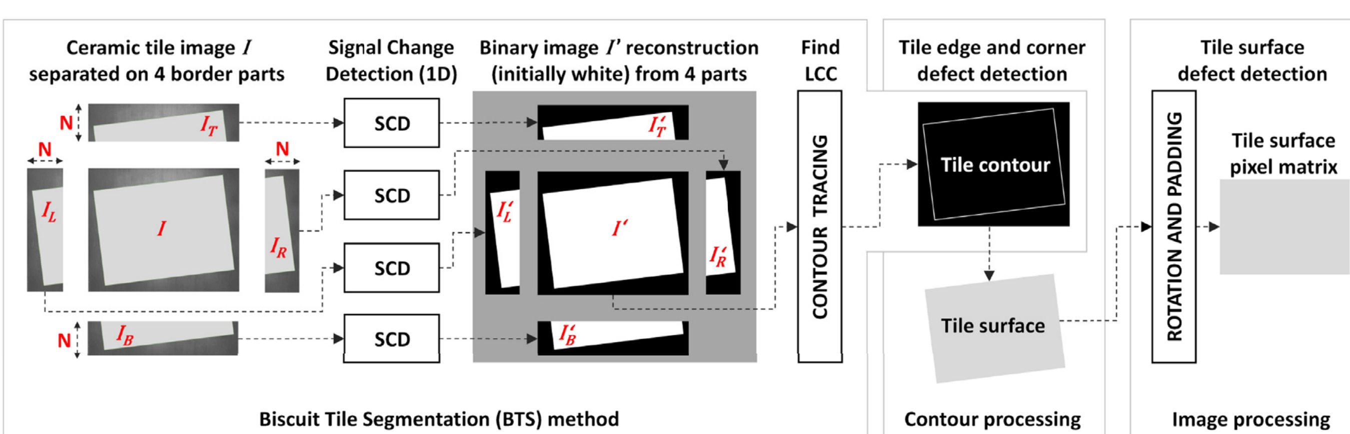

Fig. 2. Biscuit Tile Segmentation (BTS) method with Signal Change Detection (SCD) binarization and contour tracing for finding the Largest Connected Component (LCC), edge and corner defects detection and surface defects detection.

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