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A novel matching algorithm for splitting touching rice kernels based on contour curvature analysis

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ABSTRACT

A novel node matching algorithm based on contour shape characteristics is introduced for accurately separating touching rice kernels. The original images of touching rice kernels are obtained by a scanner and preprocessed by de-noise, segmentation and contour extraction operations. The extracted contours are then smoothed by convoluting with Gaussian kernel function. Curvature analysis is used to detect characteristic touching points on the boundaries. The first-derivative of the curvature curve is taken to find its local peaks. The computed extremum of curvature correspond to the touching nodes along the original boundaries. Finally, the node matching rules including the confidence radiation region, the shortest distance, the length limitation of splitting line, etc., are proposed to determine an appropriate splitting line between related two of those nodes. The rules are key procedures for dealing with the problems of splitting complex touching kernels, and thus the process of how to determine the splitting line between touching kernels is detailedly discussed. One hundred scanning images with different shapes and sizes of rice kernels are used to estimate the robustness of the algorithm. Experimental results are encouraging that the proposed algorithm is not influenced by the exogenous parameters of rice kernels and can be used to effectively split kernels touching in a very complex way. The proposed methods can eliminate the traditional limitations of the manual placement of rice samples in a non touching manner before image acquisition and implement automatic system for the subsequent inspection of the appearance quality parameters of rice.

1. Introduction

Machine vision techniques have become popular in the investigation of rice quality in recent years (Costa et al., 2011; Shao et al., 2012; Liu & He, 2009; Wu et al., 2011). Numbers of algorithms of digital image process have been introduced to analyze the quality of rice, for example, the determination of the geometrical parameters (length, perimeter, projected area, etc), the broken ratio (Lloyd et al., 2001; Yadav and Jindal, 2001; Lin et al., 2012a,b), the whiteness (Liu et al., 1998a,b) and the fissures of rice kernel (Lan et al., 2002; Lin et al., 2012a,b). All previous works show perfect performance, however, one weakness of these studies was that the algorithms required the non-touching placement of all kernels. Under the touching condition, it is obvious that most of the former algorithms of feature extraction of kernels, i.e. the estimation of perimeter, broken ratio, etc. are prone to making mistakes. Therefore, before image collection, the grain kernels must be manually placed in a non-touching form. The procedures were quite inconvenient and time consuming. So it is necessary and urgent to develop an effective algorithm for splitting touching grain kernels in images, and thus the limitations of the placement of rice kernels can be eliminated in the process of image acquisition.

Significant progress has been made on the problems of segmentation of touching kernels in images. Shatadal et al. (1995) developed a segmentation algorithm based on image transform discipline of mathematical morphology. They tried to separate touching grain kernels through the erosion and dilation operations. The algorithm failed when a relatively long and narrow connected region were formed by the closely touching kernels. Visen et al. (2001) proposed a different approach based on the contour curvature analysis to segment occluding groups of grain kernels. The contour curvature values below a certain threshold were selected as splitting nodal points. The splitting lines between two of the nodes were determined only by the 'nearest-neighbor criterion', which limited to deal with the simple touching cases with maximum of three touching kernels. Zhang et al. (2005) employed an ellipse-fitting algorithm to separate touching grain kernels. Sample

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points for fitted ellipses were found by randomly tracking the edge of touching kernels. The fitted ellipses were generated by a direct least-squares ellipse-fitting method, and then the clustering algorithm was employed to identify the best representative ellipse for each touching kernel. Finally, the touching grain kernels could be separated by the mathematical morphology transform. Such an algorithm demanded the kernels with approximately regular ellipsoid shapes, otherwise the splitting rate decreased. Wang and Chou (2004) developed an active contour model and inverse gradient vector flow (IGVF) field to segment touching rice kernels. IGVF was proposed to automatically generate a field center for individual rice kernels in an image. These centers were used as the references for setting initial deformable contours for building an active contour model. The algorithm could reconstruct the whole contour and achieve more than 96% similarity compared with the original contours. An alternative watershed transform approach has been reported for digital image segmentation. Initially, the splitting results were unsatisfying due to the over-segmentation reason (Bleau and Leon, 2000). Several approaches have been developed to solve the problems. However, it still had difficulties to separate the elongated grains in images (Casasent et al., 2002; Wang and Paliwal, 2006). In addition, those reported methods were also limited to the applications of splitting scenario of simple touching kernels. The watershed method was further improved by Zhong et al. (2009). Firstly, the distance and watershed transforms were used. Secondly, the watershed post-processing of over-segmentation was carried out by utilizing the convex features of related shapes. Thirdly, the candidates for splitting lines of touching clusters were found by matching the concavities and the rest of the un-segmented. Finally, several supplementary criterions were used to determine the splitting line. The results showed it could be employed to split the multiple clustered slender-particles. Mebatsion and Paliwal (2011) employed an elliptic Fourier series approximation to separate touching grain kernels. Nodal points were determined by the extrema of the contour curvature. A nearest-neighbour and radian critical (cumulative) distance difference of the chain-coded boundary point criteria was introduced to determine the segmentation lines between two nodal points. The algorithm appeared to be unsatisfactory when the kernels had rough boundaries or under the complicated touching condition. Park et al. (2013) introduced a robust approach that enabled automated morphology analysis of partially overlapping nanoparticles in electron micrographs. The splitting performance of the proposed algorithms showed pretty good. In Park's study, the contours of segmentation objects needed to be assumed to be convex, however, the contour of polished rice kernel nearby the germ has concave shapes. Thus, Park's algorithms were not suitable for the cases of segmentation of the rice kernels.

It is noteworthy that there were several splitting algorithms which were available for separation of rice kernels in images (Wang and Chou, 2004; Zhong et al., 2009), however, the current paper focuses on coping with the previously unsolved problems of splitting larger-scale touching kernels in images based on contour curvature analysis. To overcome the major splitting difficulties, novel matching rules including the confidence region of radiation, the shortest distance, the length limitation of splitting line, etc., for accurately determine the splitting line between two of the nodal points are proposed. As far as we know, this approach has not been reported, and that is the main motivation of writing this paper and the most significant parts of our work.

The paper is organized as follows. Firstly, experimental equipment and procedures are introduced. Secondly, methods of image preprocessing, smoothing, locating curvature peaks and node matching are presented. Thirdly, several illustrative examples of splitting simple and multiple touching rice kernels in images are discussed. Finally, draw conclusions.

2. Experiment and methods

2.1. Experiment

All of the experimental images were acquired by an HP LaserJet M1005 MFP with an optical scan resolution of 1200 dpi at 24 bits depth in grayscale style. The algorithms were performed in Matlab R2009a (The Math Works, Natick, USA) automatically.

Rice samples were placed on the glass plate of the scanner and covered with a piece of black board to acquire an image. Two kinds of touching images of rice kernels were investigated, including the simple and complex touching cases. Simple touching scenario was that just a few clusters were placed touched one by one and without holes (black backgrounds) inside shown in Fig. 1(a). Complex touching scenario was that dozens of rice kernels were placed closely, which led to some kernels and black holes surrounded by part of kernels shown in Fig. 1(b). One hundred images of slender and round rice kernels (each type contained 50 images) were collected for validation of the proposed algorithms. These images consisted of simple or complex touching cases. The details about the datasets of touching rice kernels were shown in Table 1.

2.2. Methods

2.2.1. Image preprocessing

Image segmentation is an important step in the image processing technique. The obtained scanning image is an intensity image. The intensity image is firstly converted into the binary image using the Otsu's method (Otsu, 1979; Moghaddam and Cheriet, 2012) which chooses the threshold to minimize the interclass variance of the black and white pixels. Image segmentation is an important step in the image processing technique. In our study, the contrast of intensity between the regions of the white rice samples and black background is strong, so the binarization segmentation errors might seldom arise. In spite of this case, the morphological smooth operation (e.g. a dilation following by an erosion using the same flat, disk-shaped structuring element with the radius of 8 pixels) has yet been implemented to remove the unforeseen noise from images. Due to implement of above strategy, the good performance of segmentation had been achieved. In practice, the segmentation errors might be mainly caused by the noise during imaging. It was suggested that the noise could be removed by using the classical filter technologies such as Gabor (Chen et al., 2011) and Wavelets functions (Lin et al., 2012a,b). It is inevitable that a little segmentation errors might appeared during the binarization process. These errors would add the noise on the contour curve. In order to remove the noise, the contour curves were

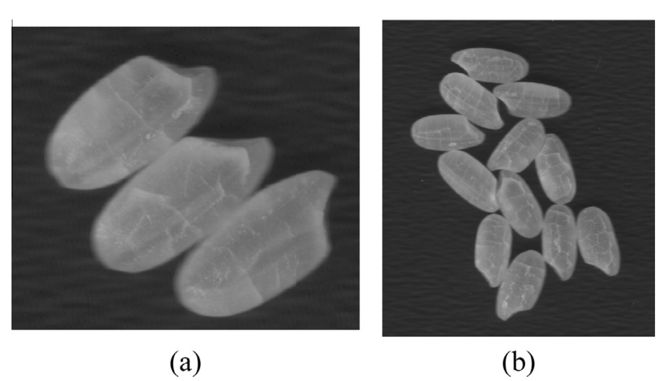

Fig. 1. (a) The simple touching scenario in which rice kernels touched one by one and (b) the complex touching scenario in which some rice kernels and black holes (black backgrounds) were surrounded by part of kernels.