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Application of statistical modeling of image spatial structures to automated visual inspection of product quality

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ABSTRACT

Automated visual inspection (AVI) attracts increasing interest in product quality control both academic and industrial communities, particularly on mass production processes, because product qualities of most types can be characterized with their corresponding surface visual attributes. However, many product images in AVI systems are comprised of stochastically accumulative fragmentations (particles) of local homogeneity, without distinctive foregrounds and backgrounds, which brings great challenges in computer analysis, e.g., rice images, fabric images, and consequently, in the intelligent identification of the product qualities. A method of Weibull distribution (WD)-based statistical modeling of image spatial structures (ISSs) to inspect automatically the product quality is presented. The ISS, obtained with multi-scale and omnidirectional Gaussian derivative filters (OGDFs), was demonstrated to be subject to a representative WD model of integral form based on the theory of *sequential fragmentation* in advance. The WD-model parameters (WD-MPs) of the ISS, with essential human perceptual significance, were extracted as the visual features for product quality identification. The classification performance of the proposed product quality inspection method, namely, the proposed WD-MP features integrated with an introduced spline regression (SR) classifier in this study, was verified on two case studies in the field of the AVI of product quality, namely, automated rice quality classification, and intelligent fabric quality assessment in the corresponding assembly lines of industrial scale. Experimental results indicate that the proposed WD-MP features can effectively characterize the statistical distribution profiles of ISS of complex grain images, piled with a large number of stochastically accumulative fragmentations. The proposed method provides an effective tool for grain image modeling and analysis and consequently lays a foundation for the intelligent perception of product qualities on assembly lines.

1. Introduction

Product quality [1,2] is the driving force for every enterprise to stay competitive in modern industrial production. Product quality monitoring is basically performed by testing the performance of the product as well as by accessing the attributes of its appearance, flavour, internal structure, and so on, both to avoid the possible defects in products and guarantee the customer satisfaction [3]. Considering that product qualities of most types can be characterized with corresponding surface visual attributes, the visual appearance, including the attributes of color, size, surface coarseness and variety of defects of the product surface, is an effective and direct sensory indicator for product quality inspection or production condition monitoring to a certain extent. Hence, automated visual inspection (AVI) of product surface plays an important role in industrial manufacturing, safety monitoring, and product quality control [4].

During the past decade, considerable efforts have been devoted to visual sensors-based AVI for product quality control or working condition monitoring in diverse industrial processes, e.g., automotive component manufacturing and assembling [5], food processing [6],

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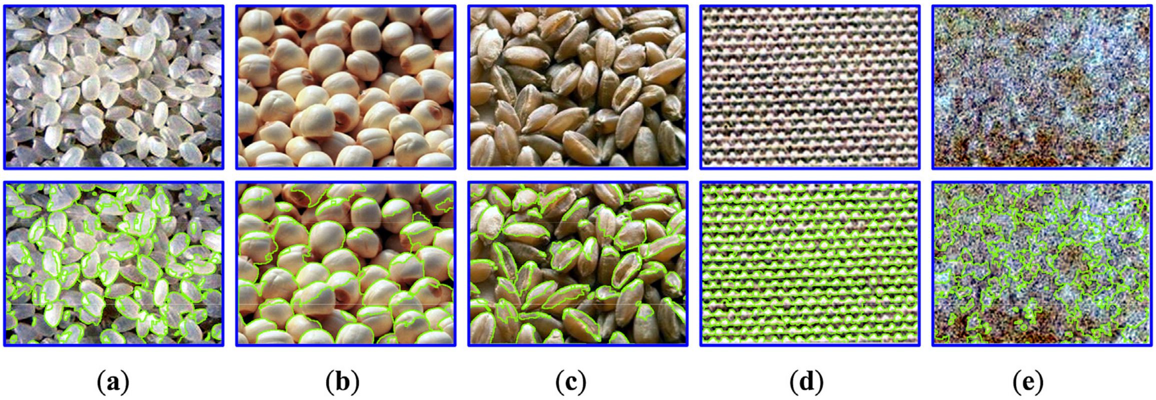

Fig. 1. Diverse product images of filling up with local region-homogenized fragments without distinct foreground objects and background regions in the first row with their best, but still unfaithful segmentation results in the second row by the famous watershed algorithm [14] integrated with the morphological grayscale reconstruction method [15]. (a) Rice grain image; (b) lotus seeds image; (c) wheat grain image; (d) fabric image; (e) ceramic tile image.

semiconductor production [7], fabric quality inspection [8], nonferrous metallurgy [9,10] and many other industrial production processes [11–13]. Intelligent online AVI systems are in imperative demand, particularly on mass production lines.

A typical AVI process mainly includes steps of image acquisition, image analysis and feature extraction, and the ultimate product quality classification or working condition recognition. Recent advances in visual sensors and image analysis technologies brought flourishing academic researches and engineering applications by providing low cost, non-destructive, flexible, efficient and integrated online monitoring tools. In view of their functions, the existing AVI systems can be categorized into two types. One is used to measure the physical properties, e.g., dimensions, colors, and shapes, of the inspected products, and the other is applied to inspect the product qualities or perceive the working conditions intelligently.

In terms of quantitative measurement, the objects to be measured or monitored in the majority of real applications can be clearly distinguished with regular geometric shapes and the corresponding monitoring images have distinct foregrounds (objects) and background regions. Thus, common image processing methods, e.g., image enhancement, edge detection, image segmentation, can achieve satisfactory processing results, and consequently, the expected physical attributes of products can be extracted effectively for products attribute measurement and furthermore for product quality assessment.

Nevertheless, monitoring objects in product quality inspection or working condition perception in quite a lot of applications are possibly composed of a large number of small visual structures (grains, cells, particles or local fragmentations) randomly distributed in the viewing field. Consequently, the captured images do not have distinct foreground and background, such as rice images, corn images in food processing factories for food quality inspection. Hence, the physical attributes of individual objects from these grain images cannot be extracted efficiently and credibly. Fig. 1 displays five kinds of typical grain images of this type, captured from the assembly lines of rice processing, lotus seed screening, wheat seed grading, fabric production and ceramic tile production.

As can be seen from Fig. 1, these grain images are composed of a large number of locally homogeneous fragmentations (or particles) of a random arrangement, without distinct foreground objects and background regions. It remains challenging to establish an effective image segmentation method to analyze these images. The unfaithful image segmentation results with time-consuming processing algorithms can be seen in the second row of Fig. 1. Thus, it is very difficult to delineate the independent particles or fragmentations of local homogeneousness in these grain images, in view of the deficiencies in the segmentation results and the time costs of the image processing procedures. In other words, the common image segmentation-based visual feature extraction methods are not highly suitable for the analysis of this kind of grain images in the AVI.

It is worth noting that, the essential perceptual information from these grain images for AVI should not be simply attained with a certain fragmentation or a few particles, but should be synthesized from the global visual appearance of ISS, which is reflected by the spatial distribution or the organization of the fragmentations (particles) as well as the shapes of the local visual patterns (fragmentations) in the observation field. This kind of fragmentation shape and distribution-related visual feature can be essentially attributed to a kind of texture characterization [16], ubiquitous in images, but deficient in the definition and difficult to be perceived by computers.

The texture characteristics are inevitably related to the statistical methods. The early widespread methods are the statistics characteristics of images, such as the first order statistics based on some measures, e.g., gray level co-occurrence or difference histograms [17], second order statistics, e.g., Fourier power spectrum [18], gray level co-occurrence matrix (GLCM) [19]; gray level run length matrix (GLRM) [20], and local binary pattern (LBP) [21], multivariate image analysis (MIA) [3], as well as their varieties. These methods do not assume any probability model of the ISS, whereas they attempted to extract some first or second statistics at a special transform domain of the image pixel to characterize the visual appearance of ISS. The results are possibly misled or confused by the extracted statistics in some extreme circumstances. For example, we can get the same sample statistics from two sample groups, which actually come from different distribution models.

As research continues, many experts devoted considerable effort to the probabilistic model-based methods to interpret ISS, especially integrated with the prevalent multi-channel image analysis technologies [22], such as Wavelet transform and Gabor filtering. Many useful statistical distribution models are introduced to do statistical modeling of images, especially in the multiscale oriented representation based on some basic assumptions, e.g., the independent distributed, and homogeneous spatial assumptions.

Specially, researches adopted long-tailed distribution models, e.g., Gaussian mixture model, generalized Gaussian distribution [23], to characterize the marginal distribution of the wavelet coefficients, owing to the sparse behavior of the wavelet coefficients. Namely, the marginal distributions of wavelet coefficients are highly kurtotic. The higher order marginal statistics, e.g., the joint distribution representing the statistical correlations of the pixels in adjustable distances and fixed orientations, is subsequently investigated by augmenting a simple