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Using perceptual relation of regularity and anisotropy in the texture with independent component model for defect detection

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Abstract

This paper addresses the raw textile defect detection problem using independent components approach with insights from human vision system. Human vision system is known to have specialized receptive fields that respond to certain type of input signals. Orientation-selective bar cells and grating cells are examples of receptive fields in the primary visual cortex that are selective to periodic- and aperiodic-patterns, respectively. Regularity and anisotropy are two high-level features of texture perception, and we can say that disruption in regularity and/or orientation field of the texture pattern causes structural defects. In our research, we observed that independent components extracted from texture images give bar or grating cell like results depending on the structure of the texture. For those textures having lower regularity and dominant local anisotropy (orientation or directionality), independent components look similar to bar cells whereas textures with high regularity and lower anisotropy have independent components acting like grating cells. Thus, we will expect different bar or grating cell like independent components to respond to defective and defect-free regions. With this motivation, statistical analysis of the structure of the texture by means of independent components and then extraction of the disturbance in the structure can be a promising approach to understand perception of local disorder of texture in human vision system. In this paper, we will show how to detect regions of structural defects in raw textile data that have certain regularity and local orientation characteristics with the application of independent component analysis (ICA), and we will present results on real textile images with detailed discussions.

Keywords: Human vision; Texture defect detection; Independent component analysis; Receptive fields

1. Introduction

Texture defect detection problem played a significant role for quality control in the production phase of goods and attracted the attention of researchers for many years. Although there are some dedicated methods that work well for certain type of textures, they often fail when different type of texture is given. On the other hand, defect detection ability of a human observer is far superior to current algorithms and works even when the observer sees that texture type for the first time. To understand the process of perception of texture, Rao and Lohse [1] revealed in their classical experiment, that regularity and anisotropy play a significant role as high-level features for texture perception by humans. The anisotropy in this nomenclature can be defined as the directionality or the orientation field in the texture. Every periodic pattern has one or more characteristic directions defined by its periodicity vectors which identify directionality (anisotropy) of the texture. Regularity, on the other hand, is known as the opposite of randomness corresponding to a higher-level organization of the structure of the texture with a repetitive deterministic intensity pattern. From this motivation, disturbance of the regularity and/or the orientation in the structure of the texture can guide us in detecting the

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defects and there are successful algorithms in the literature that make use of this idea such as Ref. [2]. Here, we will try to relate the properties of human vision system with these high-level features by means of independent component analysis (ICA) so as to achieve defect detection in texture structure.

First attempts to understand human vision system and birth of experimental psychology later called "psychophysics" dealt with changes in the mental state due to given input to the brain (a black box) such as a light beam. These studies were later supported by neuro-physiological works and after Hubel and Wiesel's pioneering experiments [3,4] growing attention of scientists was focused on the properties of the neurons that act as receptive fields in the primary visual cortex. It was shown in these experiments that these receptive fields are localized in time and space, have band-pass characteristics both in spatial and temporal domains and are selective to certain orientations. This idea being as the pivoting point, Barlow [5] proposed that these receptive fields act like some redundancy reduction mechanism and produces factorial coding of the input data. Hence the factorial coding and oriented-edge selective receptive field idea merged together and Field [6] claimed that these receptive fields enable sparse representation of the input data. Thus, only a few features are needed to be active for representing an image and for a group of images a particular feature will rarely be active. This theory later was tested experimentally by Olshausen and Field [7,8] by using a network that maximizes the sparseness of the input data coming from patches of natural images. These works were also supported by Bell and Sejnowski [9] and Hurri's [10] papers, however they used ICA, which aims to search for factorial coding of the data by finding mutually independent components. It is shown in Ref. [8] that ICA and maximization of sparseness for input data actually are related. Afterward van Hateren and van der Schaaf [11] quantitatively compared the properties of independent component filters and receptive fields in primary visual cortex. They showed that the properties of the independent component filters obtained by ICA on a large set of natural images resemble properties of the receptive fields of simple cells in macaque monkeys' cortex, which indicates that expected statistics of the natural stimuli in the environment affects the characteristics of receptive fields. Although the independent component model lacks many aspects of simple cells such as contrast adaptation [12] and nonlinearities in orientation tuning [13], it has clear information theoretical conclusions that based on statistics of stimuli. Furthermore, it can be said that receptive fields work to decompose and reduce the information redundancy in the scene that fall onto retina for different specialized tasks such as edge detection or contrast adjustment. With the same incentive, we will try to apply ICA to extract statistical properties of texture images, rather than natural images, for detecting underlying defects by reducing redundancies and decomposing texture images into independent components, which may help us to represent them in a lower-dimensional space.

In previous works on ICA, researchers tried to come up with a common representation basis for getting general statistics of the environment. Hurri [10] showed in his work that independent components of natural and texture images appeared to be different from each other. The reason for this difference is due to different nature of the statistical characteristics of natural and texture images. Hurri in his experiments used various types of texture images from Brodatz image database. Since each type of texture has drastically different structural properties, representing different textures with common independent components was infeasible. In our work, we extract independent components for each texture separately for analyzing its own structure. We observed that depending on the texture type, independent components are similar to bar or grating cells defined in Refs. [14,15] which give clues about regularity and anisotropy of the texture. Briefly we can say that, grating cells are selective for periodic oriented patterns. This is why they detect exclusively oriented texture and do not respond to contours, edges. On the other hand, bar cells are selective to oriented edges or contours (i.e., bars) that are not part of a periodic pattern. Different from the simple and the complex cells, grating and bar cells are periodic- and aperiodic-pattern selective cells, respectively. Since the structural properties of the raw textile data is formed by combination of the periodicity and the orientation features and also a defect can be defined as disruption of the structure of the texture, the idea to relate these cells with defect detection problem becomes intuitive. Even though, it is known that bar and grating cell models exhibit nonlinear behavior, they can guide us in understanding the relation of the independent components with the structure of the texture in defect analysis.

From image processing point of view, we can classify defects in raw textile data into three categories: intensity defects, geometric defects and mixture of both. Intensity defects (Refer to Fig. 1(a)) are more easily detected by a human observer than geometric errors. We observed that independent components similar to bar cells respond to intensity defects when there is an imperfection in the structure of the texture rather than responding to texture itself. That probably explains why intensity defects catch the attention of an observer, regardless of the texture type. For geometric defects (refer to Fig. 1(b)), studies of von der Heydt et al. [14] revealed special cells called grating cells in the early vision system that respond to both orientation and periodicity of the given pattern and Petkov and Kruizinga [15] simulated these findings for texture detection and noted that these cells just respond to textured areas in a given scene and respond weakly or do not respond at all to an input image which contains non-texture image attributes. Thus, grating cells and bar cells can be thought of as higher-level processor units in the visual system that respond to regularity and orientation of the texture's structure, and this can be used as a model for texture analysis. From this point, we expect geometric