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Illumination-insensitive texture discrimination based on illumination compensation and enhancement

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ABSTRACT

As the appearance of a 3D surface texture is strongly dependent on the illumination direction, 3D surface-texture classification methods need to employ multiple training images captured under a variety of illumination conditions for each class. Texture images under different illumination conditions and directions still present a challenge for texture-image retrieval and classification. This paper proposes an efficient method for illumination-insensitive texture discrimination based on illumination compensation and enhancement. Features extracted from an illumination-compensated or -enhanced texture are insensitive to illumination variation; this can improve the performance for texture classification. The proposed scheme learns the average illumination-effect matrix for image representation under changing illumination so as to compensate or enhance images and to eliminate the effect of different and uneven illuminations while retaining the intrinsic properties of the surfaces. The advantage of our method is that the assumption of a single-point light source is not required, so it circumvents and overcomes the limitations of the Lambertian model and is also suitable for outdoor settings. We use a wide range of textures in the PhoTex database in our experiments to evaluate the performance of the proposed method. Experimental results demonstrate the effectiveness of our proposed methods.

1. Introduction

The appearance of rough surface textures may be dramatically different when they are lit from different directions. For example, Fig. 1 shows images of the same surface texture captured under varied lighting directions. They look dissimilar mainly due to the different illumination directions. Although it is well known that the appearance of a texture is strongly dependent on the illumination directions, dealing with illumination-insensitive texture is still an open issue and worth further investigation [8,9,37,39].

As a special type of image, texture can describe a wide variety of surface characteristics. Texture is very important for human visual perception and plays a key role in computer vision and pattern recognition. In addition, since texture can be effectively used for characterizing image regions, texture features have been extensively studied in image classification and content-based image retrieval, as well as in other fields related to pattern analysis [8,9,21,22,38].

Traditionally, texture-representation methods can be divided into three categories, namely structural [34], statistical [17,26], and multi-resolution filtering methods [14,19,24,27–29,36]. These methods have been effectively used for texture analysis, segmentation, retrieval and classification [1,8]. However, most of these previous methods focus on texture-feature

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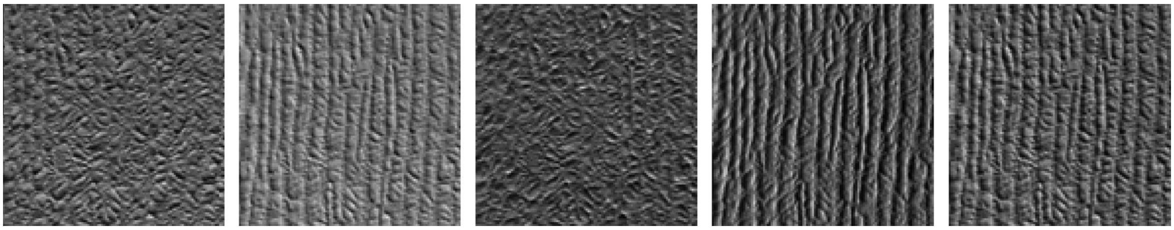

Fig. 1. Textures under different illumination directions: five texture images of the same surface, "acg", from the PhoTex database.

representations, and seldom make further analysis of texture images captured under different illumination directions; yet variations in lighting directions can make the same texture look dissimilar. In this paper, we will focus on the problems associated with the effect of illumination variations on texture images. This paper proposes a method that can compensate for or enhance illumination in an original texture image so that features that are insensitive to illumination variation can be produced. According to our method, texture-feature extraction is performed after illumination compensation or enhancement has been applied to the original surface texture. This can alleviate the effect of different and uneven illuminations, and render the extracted feature "illumination-insensitive". In this paper, we will focus on the problems associated with the effect of illumination variations on texture images. The main contributions of this paper are:

- two novel methods, namely the illumination-compensation algorithm (ICA) and the illumination-enhancement algorithm (IEA) are proposed for illumination-insensitive texture discrimination; and
- the assumption of a single-point light source is not required, so it circumvents and overcomes the limitations of the Lambertian model and is also suitable for outdoor circumstances.

The rest of the paper is organized as follows. Related work is presented in Section 2. In Section 3, we describe our proposed methods for illumination compensation and enhancement. Experiment results will be presented in Section 4, and a conclusion and discussion are given in Section 5.

2. Related work

A surface texture captured under different illumination directions may involve some difficult problems, as the appearance of the same surface can change dramatically. Illumination variation is still one of the most prominent issues for appearance- or image-based recognition approaches, although a number of researchers have paid great attention to relevant solutions. The first type of method in this research field uses a number of texture images captured under different illumination directions to extract the three-dimensional shape of the texture for illumination-insensitive representation [7,10,12,23,30]. In [18], it was found that the ratio of two images of the same object is simpler than the ratio of images of different objects with Lambertian reflectance, and that the ratio also provides two of the three distinct values in the Hessian matrix used to represent the object's surface. Another method based on quotient images was introduced in [33], which assumes – based on the Lambertian model – that faces in the same class have a similar shape but different textures. In [6], it was found that, with surfaces of uniform albedo, it is possible to make two images of a surface observed under two different illumination directions have a similar appearance; Chen et al. in [6] employed the joint probability of image gradient directions to compute the likelihood that two images come from the same surface. Chantler et al. [4] and Barsky [3] employed an illumination model to deal with this problem: they showed that the variance of the response of a filtered image under varying illumination tilt angles is sinusoidal. Barsky [3] computed statistical surface descriptors from photometric stereo data, and generalized Chantler's approach to non-uniform albedo materials and general lighting directions. Both of these works use the variance of images filtered by linear operators as features. Osadchy et al. [31] achieved illumination quasi-invariance on smooth surfaces using the whitening approach. Their assumptions are that the surface is Lambertian with uniform reflectance and shallow relief, and that the illumination direction is sufficiently inclined from the surface macro-normal. The method is applied for the classification of registered images of smooth objects. However, it is not easily extendable for texture recognition, as its effect increases the dissimilarity between images coming from different objects, rather than making the images produced by the same surface more similar [31]. Drbohlav and Chantler [11] proposed a novel method which is different from previous work in such a way that it can make two images of the same surface virtually identical. The method hypothesizes that it can match image statistics of the same surface texture observed under different illumination conditions; this idea was applied to comparing texture images for classification. Recently, Barsky and Petrou [2] proposed statistical surface descriptors using photometric stereo data based on a generalized sinusoidal model, which can capture variations in texture features due to changed illumination directions. Traditional illumination-insensitive methods for image representation are based on the Lambertian assumption, and construct a 3-D surface representation by using a number of the images captured under different illumination directions. However, there are two obvious drawbacks with the Lambertian model: a single-point light source placed at infinity is assumed, and multiple images need to be captured under a variety of illumination conditions for each surface so that a 3-D representation can be obtained. Even though the Lambertian model is suitable for some