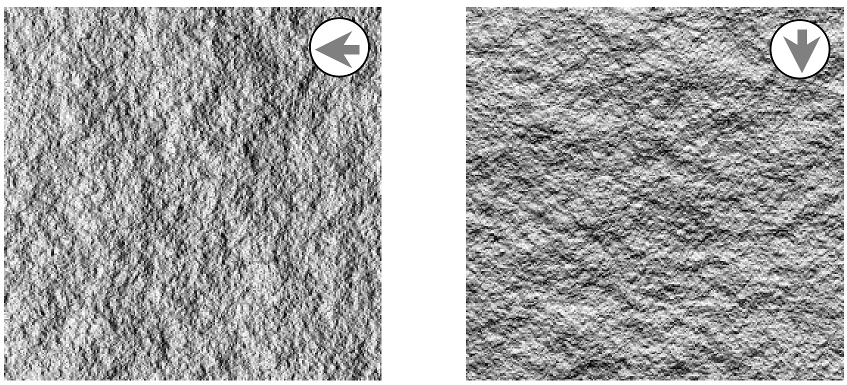
CHAPTER 1

Introduction

1.1. Motivation and Background

Many texture classification scheme have been presented that are invariant to image rotation [Cohen91] [Mao92] [Haley96] [Porter97] [Pietikainen00]. They normally derive their features directly from a single image and are tested using rotated images. If the image texture results solely from albedo variation rather that surface relief or if the illumination is not directional or immediately overhead, then these schemes are surface-rotation invariant as well. However, *3D* surface textures are often illuminated from one side when they are photographed in order to enhance their image texture, e.g. [Brodatz66]. Such imaging acts as a directional filter of the *3D* surface texture [Chantler94]. This phenomena is illustrated below. *Figure 1. 1* shows the same sample of *3D* surface texture imaged using two different illumination conditions.



$\tau = 0°$ $\tau = 90°$

Figure 1. 1 Images of the same 3D surface texture imaged at two different illuminant tilt (τ) directions shown by the top-right arrows.

The directional filtering effect is more obvious in the frequency domain. *Figure 1. 2* shows the Fourier transforms of the two image textures shown above. This shows more clearly that side-lighting accentuates texture components in the illuminant tilt direction *(τ)* and attenuates those at right angles.

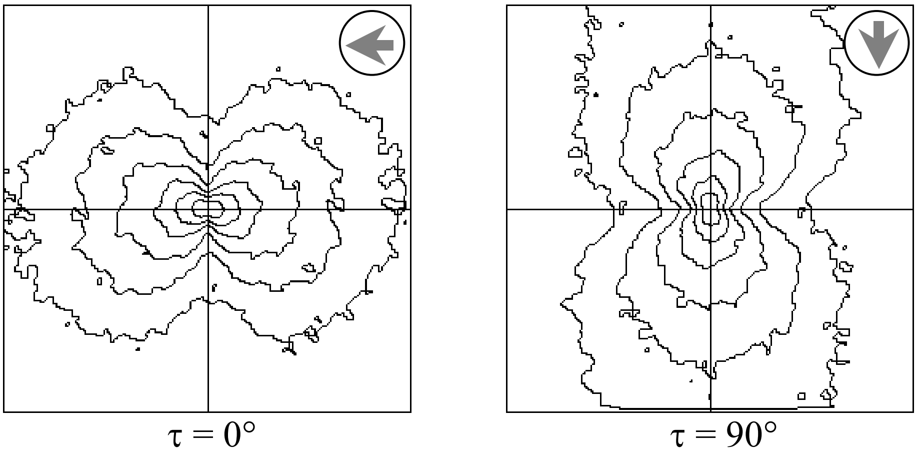
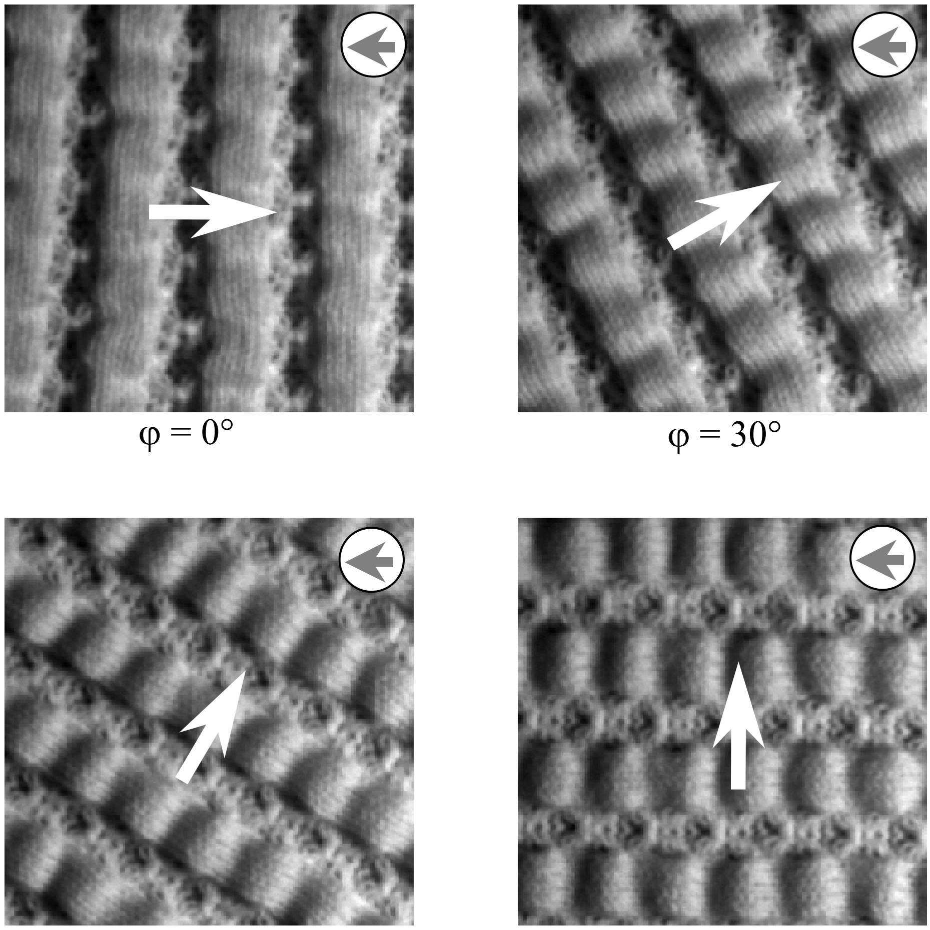


Figure 1. 2 FFTs of the image shown in Figure 1. 1.

In many cases rotation of a textured surface produces images that differ radically from those provided by pure image rotation (see *Figure 1. 3*). These images show that rotation of a *3D* surface texture does not result in a simple rotation of the image texture. Rotation of the physical texture surface under fixed illumination conditions can also cause significant changes to its appearance. This is mainly due to the directional filtering effect of imaging using side-lighting [Chantler94a, Chantler94b]. It also causes failure of classifiers designed to cope with image rotation [McGunigle98].

We have shown that rotation of a rough surface is not equivalent to rotation of its image, and that conventional rotation-invariant algorithms may fail under these conditions. The aim of this thesis is therefore to develop a new classification scheme that uses surface information derived from photometric stereo to provide a surface rotation invariant classifier.



φ = 0° φ = 30°

φ = 60° φ = 90°

Figure 1. 3 Four images of a directional 3D surface texture rotated at angles of φ*=0°, 30°, 60° and 90° (indicated by the center white arrows). The illuminant tilt is kept constant at* τ*=0° (indicated by the top-right black arrows in white circles).*

1.2. Scope of Research

The surface is considered to lie in the *x-y* plane. Furthermore, this work uses a linear reflection model based on Kube and Pentland's linear model [Kube88]. The surface reflectance is therefore considered to be diffuse, and uniform throughout the surface. The light incident on the surface is considered to be parallel and of equal intensity across the imaged region. The imaging device is assumed to be a monochrome CCD camera located directly overhead the surface texture sample. Finally, we assume the topography of the surface is small relative to the distance between the camera and the surface, and that the projection of the surface onto the CCD array is orthographic. In general, the imaging geometry is illustrated in *Figure 1. 4*. The test surface is mounted in the *x-y* plane and is perpendicular to the camera axis *(z-axis)*, and the surface is illuminated by a point source located at infinity. The surface rotation is measured in the *x-y* plane.

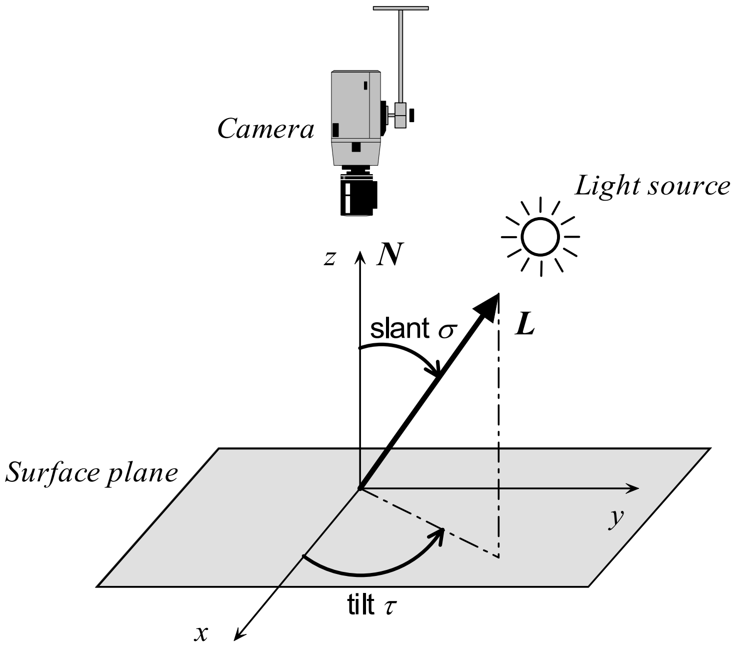


Figure 1. 4 Imaging geometry.

All of the classifiers considered in this thesis ignore phase information and discriminate on a sampling of the power spectrum of either surface derivatives or surface albedo.

1.3. Original Work

It is believed that this thesis represents three main original contributions to the field of rotation-invariant texture classification:

- Regarding the texture database, we note that currently existing and publicly available ones [Brodatz66] [Dana99a] [Ohanian92] [Ojala96] are not suitable for our research, as they can not provide registered photometric stereo data set for surface textures. The texture due to surface roughness has complex dependencies on orientation, viewing and illumination direction. These dependencies can not be studied using those texture databases that include few images of each sample. We therefore develop our novel ***photometric stereo 3D surface texture database***, which is not only concerned with surface rotation, but also with the different and controlled illuminant conditions. It covers a diverse collection of *4* synthetic and *30* natural surfaces, and it is intended to provide photometric data for the study of rotation-invariant surface texture classification.

Note that our texture database is similar to *PhoTex* database [McGunnigle01]. However, the main variables in *PhoTex* database are azimuth and zenith of the illumination. Although some surface sample are rotated, it does not provide full surface rotation samples so that it can not be used in this work.

- The recovery of an intrinsic description of a surface (e.g. surface orientation) by photometric stereo is, without any doubt, a necessary step for our surface texture classification. The *1D* feature spaces ***polar spectrum*** and ***radial spectrum*** by means of surface derivative fields in the frequency domain has been added to the benefit of accounting for surface properties. The surface orientation can also be estimated via polar spectra. Furthermore, an efficient classifier could be based directly on the new-developed feature generators ***gradient spectrum*** and ***albedo spectrum*** as they hold sufficient information on the surface topology and orientation.

- An important contribution of this thesis is the development of a complete classification scheme to reduce the effect of surface orientation changes and the effect of surface shadow on classifier accuracy. A simple strategy of ***photometric stereo using four light sources*** is therefore developed. With regarding to the classification design, a new classification scheme using ***2D feature space comparison*** is finally developed to achieve the better classification results.

1.4. Organisation of This Thesis

Chapter 2 provides a survey of research into the rotation invariant texture classification, which includes texture feature measurement, image rotation invariant features and surface rotation invariant features. We note that there are few methods in which the effect of changing illumination conditions are taken into account. In *Chapter 3* we present a short review of reflection and illumination models from surface to image. Thereafter, Kube and Pentland's surface model [Kube88], a linear Lambertian model, is identified and investigated in terms of its frequency domain response, directional filtering effect, non-linear terms and shadowing. We also demonstrate that surface rotation classification is not equivalent to image rotation classification. Photometric stereo is introduced in *Chapter 4*. It enables us to estimate surface properties rather than image properties using several images of a surface taken from the same viewpoint but under illumination from different directions. The surface derivatives obtained by photometric stereo are also examined in *Chapter 5*.

Chapter 6 proposes an algorithm for rotation invariant texture classification using polar spectra and gradient spectra obtained using photometric stereo. The surface partial derivatives obtained by a simple solution of three-image photometric stereo are combined in the frequency domain in such a way as to remove the directional artefacts. The results from both synthetic and real textures show that a rotation of the surface produces a corresponding rotation of its gradient spectrum. We note that the nature of gradient spectrum provides very useful information relating to the type of surface structure and the predominant orientation of the surface texture. Thus the surface orientation can be estimated via their polar spectra. In *Chapter 7*, we design and carry out the experimental work using *4* synthetic textures and *30* real textures to test the efficiency of the proposed classification scheme. Since currently existing and publicly available texture databases are not suitable for our tasks, we develop our photometric stereo texture database. After investigating the misclassifications described in *Chapter 7*, we introduce a new classification feature space in *Chapter 8.* The radial spectrum and a new feature generator, albedo spectra are added in order to provide more information on surface texture properties and improve the classification performance. The problem of shadowing using three-image photometric stereo is considered in *Chapter 9*. We develop a four-image photometric stereo to provide more accurate *3D* surface texture properties in the presence of shadows. At the final stage, the classifications perform on comparison of 2D spectrum.

Finally, in *Chapter 10*, the work of the previous chapters is summarised, and we present the conclusions of the thesis.