COMPENSATION OF ILLUMINANT TILT VARIATION FOR TEXTURE CLASSIFICATION

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Abstract — This paper uses theory and laboratory experiment, to show that directional illumination used during the image acquisition process, acts as a directional filter of three dimensional texture. It is shown that the directional characteristics of image texture are not intrinsic to the physical texture being imaged, as they are affected by the direction of the illumination. The implications of this to texture classification are then investigated using a set of Laws' [1] operators. Finally, a scheme for the compensation of effects caused by changes in illuminant orientation is proposed and evaluated.

1. INTRODUCTION

Texture classification normally involves three processes, Figure 1. First, the subject texture must be illuminated and its image acquired. Second, feature operators are applied to the digitised image to produce a set of feature images. It is these images that provide the numerical descriptions of the textures. Third, a set of discriminant rules (for instance, a set of statistically derived discriminant functions) are applied to classify the image into texture classes.

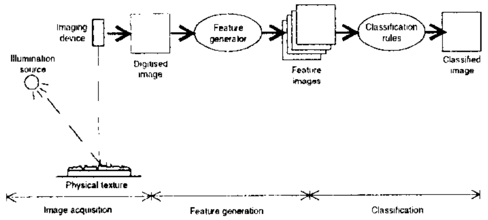

Figure 1 - The texture classification process

This paper examines the effect that the direction of the illuminant has on the directional characteristics of image texture. Firstly, it presents an image model of three-dimensional texture, which predicts that an imaging process, which uses directional lighting, acts as a directional filter of texture. Experimental findings are then presented to validate the model. The effect of tilt variation on the classification is then considered and a compensation scheme is developed and tested.

2. AN IMAGE MODEL OF THREE-DIMENSIONAL TEXTURE

This section presents a model of the image of an illuminated three-dimensional texture based on theory developed by Kube and Pentland [2] and further developed by Chantler [3][4]. Kube and Pentland's paper essentially applies a simplified version of the Lambertian surface reflectance model to an expression for the power spectral density of the fractal height-map. We shall consider the situation where the illuminant vector is not perpendicular to the reference plane of the texture surface.

2.1. A frequency domain model of image texture.

Consider a Lambertian surface illumated by a point source. The normalised image intensity I(x,y) of the surface $V_H(x,y)$ is

$$I(x,y) = \mathbf{n} \cdot \mathbf{L} = \frac{-p\cos\tau\sin\sigma - q\sin\tau\sin\sigma + \cos\sigma}{\sqrt{p^2 + q^2 + 1}} \qquad (1)$$

where

$\mathbf{n}$ = the unit vector normal to the surface at the point (x,y)

$$p = \frac{\partial V_H}{\partial x} \qquad q = \frac{\partial V_H}{\partial y}$$

$\mathbf{L}$ = (cosτ.sinσ, sinτ.sinσ, cosσ) is the unit vector towards the light source

τ and σ are the illuminant vector's tilt and slant angles as defined below.

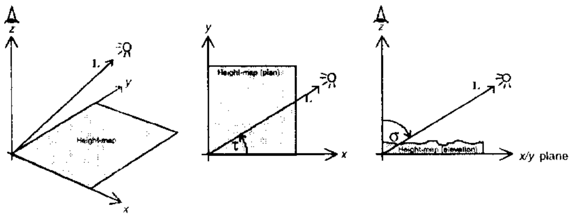

Figure 2- Definition of axis and illumination angles

Now in a departure from [2] and without loss of generality, choose a new axis (x',y',z) which is rotated τ about the z axis such that the projection of L onto the x-y plane will be parallel to the x' axis. In this new axis system the expression for intensity simplifies to

$$I(x,y) = \mathbf{n} \cdot \mathbf{L} = \frac{-r\sin\sigma + \cos\sigma}{\sqrt{r^2 + t^2 + 1}} \qquad (2)$$

where

$$r = \frac{\partial V_H}{\partial x'}, \text{ and } t = \frac{\partial V_H}{\partial y'}$$

Taking the MacLaurin expansion yields

$$I(x,y) = (-r\sin\sigma + \cos\sigma)\left[1 - \frac{(r^2+t^2)}{2!} + \frac{9(r^2+t^2)^2}{4!} + \ldots\ldots\right] \qquad (3)$$

Now if the surface slope angle is less than 15°, then $r^2, t^2 << 1$; and the quadratic and higher order terms may be neglected. Note that the error introduced by this approximation for a slope angle of 15° is 3.5%. With this approximation (3) becomes

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$$I(x,y) = (-r\sin\sigma + \cos\sigma) \tag{4}$$

which is simply the mean, plus a linear contribution of the surface gradient, measured in the direction of the illuminant's tilt angle.

Now the partial derivative operator $\frac{\partial}{\partial x'}$ is a linear operator [3], and in the frequency domain may be represented by :

$$\Im\left[\frac{\partial V_H}{\partial x'}\right] = i\omega\cos(\theta - \tau)F_H(\omega,\theta) \tag{5}$$

where

ω is the angular frequency of the Fourier component

θ is its direction w.r.t. the x-axis

$\Im[g(x,y)]$ is the two-dimensional Fourier transform of g(x,y), and

$F_H(\omega,\theta) = \Im[V_H(x,y)]$

Now, from (4)

$$I(x,y) = -\frac{\partial V_H}{\partial x'}\sin\sigma + \cos\sigma \tag{6}$$

Hence if the mean is ignored, the Fourier transform of the image intensity is :

$$F_I(\omega,\theta) = \Im\left[-\frac{\partial V_H}{\partial x'}\sin\sigma\right]$$

$$= [-i\omega F_H(\omega,\theta)][\cos(\theta - \tau)][\sin\sigma] \tag{7}$$

This is similar to the result presented in [2], except that (i) it is more general, in that it does not assume a fractal surface, and (ii) it contains simpler trigonometric terms, which enable the directional effect of lighting to be more easily understood.

2.2. Implications of the model for the directional characteristics of images

If the surface texture is isotropic, and the slant angle of the illuminant is held constant, then (7) above, predicts that the image texture will be :

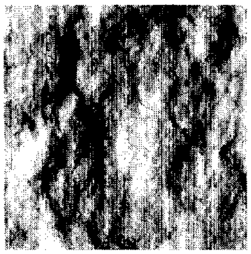
$$F_I(\omega,\theta) = \cos(\theta - \tau).k \tag{8}$$

where k is a constant.

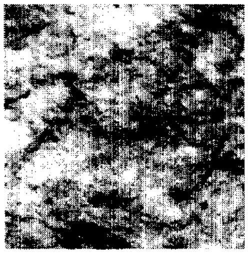
That is, the frequency components of a texture in the same direction (θ) as the tilt angle of the illumination (τ) will be accentuated compared with those components at right angles to this illumination. Thus it implies that an image forming process using directed illumination acts as a directional filter of texture. Such an effect is likely to have important implications for texture classification schemes. It implies that the directional properties of image texture are not intrinsic to the surface, but that they are considerably affected by variation in illuminant tilt. This is unfortunate, as the majority of texture feature sets used in classification and segmentation exploit directional characteristics.

3. LABORATORY EXPERIMENT - FOUR PHYSICAL TEXTURES

In this section, results of laboratory experiments are presented using real textures. The textures were first sprayed matte white to eliminate any albedo texture and to provide an approximately Lambertian reflectance characteristic and then viewed from directly overhead. The position of the illumination was varied in terms of tilt and all other parameters were kept constant. Two images of a test texture are shown below.



"rock1" (τ = 0°)



"rock1" (τ = 90°)

Figure 3 - Images of the test texture "rock1" at two angles of illuminant tilt.

The illuminant's tilt angle (τ) was varied in 10° steps over 180°. Two examples of the polar plots of the two-dimensional spectra of rock1, are shown in Figure 4. As predicted, illuminant tilt clearly has a considerable impact on directionality of image texture rock1 (note that the angular position of the magnitude peak follows τ). These empirical results therefore

(i) show that image texture directionality is not an intrinsic characteristic, and

(ii) support the $\cos(\theta - \tau)$ relationship between illuminant tilt and image texture.

The variation in the images directional characteristics caused by a change of illuminant tilt angle from 0° to 90° is discernible but not obvious. FFTs of the images showed that they were clearly directional and that the directional distribution of energy rotated with the illuminant tilt angle — the maxima always coinciding with the tilt angle as predicted by equation (8). However, although the minima do occur at τ=-90° they are not of zero magnitude as predicted by equation (8). This can in part be explained by the non-linear terms that were removed from the model when it was linearised for use in the frequency domain. The modified form of (8) was then developed with the best fit[1] raised cosine functions :

$$y = m_\tau \cos(\theta - \tau) + b_\tau \tag{9}$$

It should be noted that the other textures gave similar results to "Rock1".

These phenomena complicate the task of texture classification; as many texture measures used in such schemes exploit directional characteristics of texture. Hence the next section examines the effect that changes in illuminant tilt angle have on the accuracy of classification based on a set of texture measures, which is popular in the literature.

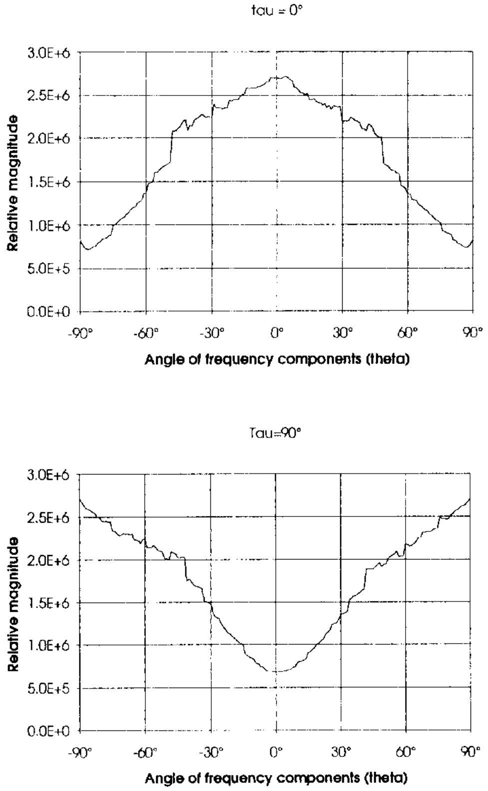


Figure 4 - Effect of illuminant tilt angle on image directionality.

4. THE EFFECT OF ILLUMINANT VARIATION ON CLASSIFICATION ACCURACY

A classifier consisting of five, 5x5 Laws measures and a linear discriminant will be used throughout the remainder of this paper. In terms of the frequency domain, the measures form a set of directional, low, band and high pass FIR filters. The classifier was trained and tested on a montage of textures illuminated at $\sigma = 50°$ and $\tau = 0°$, Figure 5, but for this experiment the tilt angle (τ) of the test sets was varied in 10° steps from 0° to 180°, while the slant was kept constant at $\sigma = 50°$.

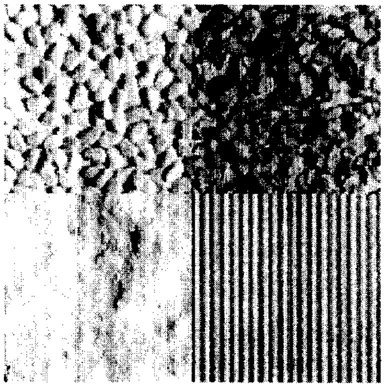


Figure 5 Test montage illuminated at $\tau = 0°$

The resulting classification error rates for the Laws1 classifier are shown in Figure 6. It shows that, for this data set, the Laws1 classifier is (i) significantly affected by variation of illuminant tilt, and (ii) that the TEC (total error of classification) is dominated by the failure to correctly classify the majority of class card1 between tilts of 50° and 120°. These results clearly demonstrate that variation of illuminant tilt between training and classification sessions can have a dramatic effect on the accuracy of a statistical classifier.

5. FREQUENCY DOMAIN TILT-COMPENSATION

This section proposes a tilt-compensation method which is based upon the frequency domain model of image texture developed earlier. The earlier experimental work produced equation (9).Thus if the illuminant tilt is known, a tilt-compensation filter of the form

$$H_{\tau c}(\omega,\theta) = \frac{1}{m_\tau \cos(\theta - \tau) + b_\tau} \tag{10}$$

may, in theory, be applied to remove variations due to changes in tilt angle. This filter must of course be applied to all test images and to all training images. It should be applied before feature generation.

Hence the main advantage of this scheme is that training images only need to be obtained under a single set of illuminant tilt conditions — as tilt-compensation filters will in theory compensate for any variations due to changes in τ.

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[1] The parameters of the raised cosine were caculated using least squares linear regression.

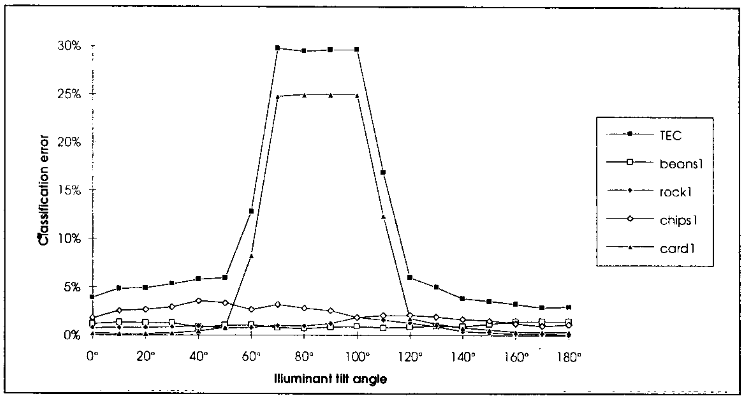

Figure 6- The effect of tilt variation on the classifier Laws1.

The coefficients m_τ and b_τ in (9) were obtained in the first instance by taking an average of estimates derived from four isotropic textures. The resulting family of tilt-compensation filters, referred to as "F1" in the following text, is defined below.

$$H_{F1}(\omega,\theta)=\frac{1}{0.6\cos(\theta-\tau)+0.6} \qquad (11)$$

Unfortunately application of this filter family to images of a test set, comprising isotropic textures, actually increased the average tilt sensitivity of the Laws' features. A closer examination revealed that only the higher frequency masks R5R5, E5L5, and E5S5 were adversely affected, which suggests that the tilt response model above is inadequate at high frequencies.

5.1. An improved frequency domain model

The model developed earlier is therefore inappropriate at high frequencies. It was observed experimentally that while the model effectively predicts power at low and medium frequencies, it overestimates the effect in the upper range. A revised model with the following characteristics was developed and designated F2.

$$\left.\begin{aligned} m_\tau &= -1.4\,\omega/\omega_s + 0.7 \\ b_\tau &= 0.8\,\omega/\omega_s + 0.6 \end{aligned}\right\} 0 < \omega/\omega_s < 0.5$$

$$\left.\begin{aligned} m_\tau &= 0.0 \\ b_\tau &= 1.0 \end{aligned}\right\} \omega/\omega_s \geq 0.5$$

5.2. Effect of tilt-compensation on classification

The experiment carried out in section 4 is now repeated using the F2 filter to preprocess the images prior to feature extraction. Figure 7 shows the results of the tilt-compensation experiment — performed with the Laws1 classifier. Comparison of these results with the equivalent uncompensated versions (Figure 6) show that the classification errors associated with the directional texture card1 have been significantly reduced. The error rates of the isotropic textures however, do not show a similar reduction.

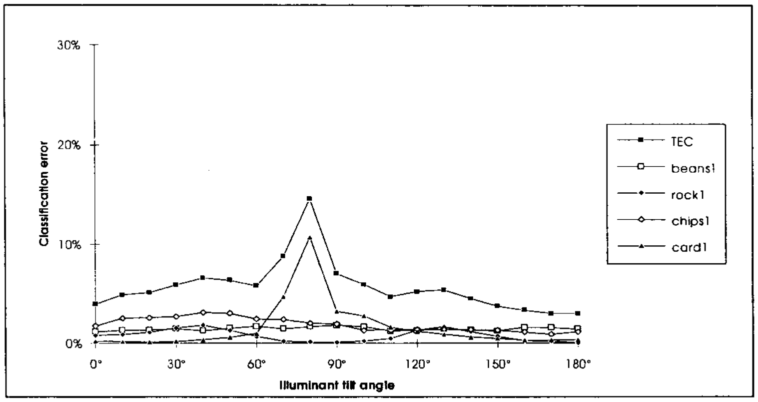

Figure 7 - The effect of tilt-compensation on the Laws1 classifier (data set : F2 tilt-compensated)

The flat graphs of error rates of the uncompensated isotropic textures, shown in figure 6, suggest that variation in illuminant tilt does not affect the appearance of these textures enough to cause significant mis-classification. Hence it is not surprising that the tilt-compensation scheme does not reduce isotropic error rates in this instance.

The main points that can be drawn from figure 7 above are :

- Tilt-compensation does reduce classification errors of the directional texture card1.
- Tilt-compensation does not significantly change the classifiers' ability to classify the isotropic textures of the test set.

6. CONCLUSIONS

This paper has presented the results of an investigation into the effect that variation in illuminant tilt angle, has on image texture and its classification. To summarise :

- Results from theory and physical experiment show that the directional characteristics of image texture are not intrinsic — but that they are heavily dependent upon illuminant tilt.
- The linear image model (7) predicts a cosine relationship : $\cos(\theta - \tau)$ for the directional characteristics of images of isotropic texture, and this is supported by the results of laboratory experiments.
- Variation in illuminant tilt between training and classification sessions significantly increased the number of mis-classifications of the directional test texture.

In addition a tilt-compensation scheme was developed. It is based upon an improved frequency domain model derived from four isotropic test textures. The scheme consists of a family of filters — one for each value of illuminant tilt. They are used to process images before feature generation at the training and classification stages. The conclusion drawn after testing this compensation scheme and comparing its results with those achieved with uncompensated images is that :

- Tilt-compensation reduces tilt related errors for the directional texture card1, and it does not degrade a classifier's ability to classify the isotropic textures.

Hence the main conclusion is that the tilt-compensation scheme reported here does offer a promising method of countering the effects of variation in illuminant tilt.

REFERENCES

1. K.I. Laws, "Textured image segmentation", Ph.D. thesis, Dept. Electrical Engineering, University of Southern California, Jan. 1980.
2. P. Kube & A. Pentland, "On the imaging of fractal surfaces", IEEE Trans. Pattern Analysis and Machine Intelligence, Vol. 10, No. 5, pp704-707, Sept. 1988
3. M.J. Chantler, L.M. Linnett, & G.T. Russell, "Illumination: a directional filter of texture?", Proc. of BMVC94.
4. M.J. Chantler, "The effect of variation in illuminant direction on texture classification", Ph.D. thesis, Heriot-Watt University, June 94.