Chapter 7

Summary and conclusions

7.1. Summary

The subjects of this thesis are : (i) the effect of variation of illuminant direction on images of topological texture, and (ii) the effect of these changes in image texture on supervised classification. In addition a tilt compensation scheme was proposed and shown to be able to reduce classification errors caused by changes in illuminant tilt between training and classification sessions.

Chapters 2 and 3 investigated (i) above. First a brief survey was presented which identified an image model of topological texture due to Kube and Pentland [Kube88]. This model was presented using a simplifying axis transformation which resulted in simpler expression for the model — providing a clearer view of its directional characteristics. It was also generalised to non-fractal surfaces. More importantly however, the implications of this model for texture classification were examined. The model predicts that the directional characteristics of image texture are not only a function of surface relief but (ignoring the more complex case uni-directional texture) are also dependent upon the tilt angle of the illumination. In addition it predicts that image variance is a function of the illuminant's slant angle. These effects are unfortunate as many texture classification schemes exploit image directionality and some exploit image variance. Variation in the latter may be removed by normalisation of images — thereby in theory removing any variations due to change in illuminant slant. Variation of image directionality due to changes in illuminant tilt may not however be compensated for in the same manner.

The third chapter used simulation and laboratory experiment to investigate the validity of this theoretical model. The results confirmed that variation in illuminant tilt can affect the directional characteristics of image texture; and that for the four isotropic test textures employed a "raised cosine" rather than the straight cosine relationship predicted by the image model was more appropriate. Future work may be able to exploit this characteristic to provide a frequency domain based illuminant tilt estimator.

The laboratory results also showed that image variance is a function of illuminant slant, but the results of simulations suggest that the predicted "sine" relationship is severely affected by shadowing. In addition the opportunity to assess the intrinsic nature of the radial shape of image magnitude spectra was taken. The gross shape of radial sections were shown to be maintained under changes in illuminant slant and tilt. However, it could not be shown that the gradient of a straight line approximating the radial section (i.e. a function of the power roll-off factor) would remain constant. Thus radial shape may, or may not, provide the basis for a practical set of texture measures that are invariant to changes in illuminant direction, but such a development must be the subject of future work.

Having established that the variance and directionality of images of isotropic texture are not invariant to changes in illuminant direction, the second part of this thesis addressed the potential impact of these variations on supervised texture classification.

Chapter 4 surveyed feature measures employed in texture classification. It identified three sets of texture measures for further investigation and in addition noted that no literature on the effects of illuminant vector variation on texture classification had been uncovered.

In chapter 5 the responses of the three sets of feature measures were investigated as regards to the effect of variation in the illuminant vector. First, the two-dimensional frequency response of the features was presented; both to provide a common view of their directionality and to give insight as to the effects predicted by the frequency domain image model presented in chapters 2 & 3. Second, this image model was used to predict the tilt response of one of Laws' feature measures — a comparison with empirical results demonstrated the image model's utility. Third, the tilt and slant responses of the features were presented. All three feature sets were affected by variation in slant. These effects were reduced by image normalisation, but this compensation was accompanied by a reduced separation between class means. The effect of tilt variation was found to depend upon the directional characteristics of the feature measure and the surface relief tested. If either were uni-directional then the output was strongly affected by illuminant tilt variation. Normalisation again reduced these effects but only if the texture was uni-directional.

Having established the effect of variation in illuminant direction on the three feature sets (as applied to the test textures) the next step was to assess the significance of these variations with respect to particular classification tasks. Hence chapter 6 introduced a simple statistical classification scheme employing a linear discriminant. This was combined with each of the three feature sets and applied to montages of isotropic and directional textures. These tests showed that variation of the illuminant's slant angle between training and classification could significantly degrade classification accuracy. Normalisation of the test sets did not markedly improve matters. Similar tests on tilt variation showed that, for the test sets employed, significant classification errors could be induced but that these were confined to the directional texture. Normalisation reduced these errors but also increased the mis-classification of isotropic textures.

The second half of chapter 6 was devoted to the development of an illuminant tilt compensation scheme. The image model developed in chapters 2 and 3 was used as the starting point from which to design a set of tilt compensation filters. In order for this scheme to be used the illuminant's tilt angle must be known during training and classification sessions — as it is used to select the appropriate filter with which to pre-process the images. Analysis of the results of employing this scheme showed that

(a) it reduced the average tilt sensitivity of all three feature sets,

(b) it reduced classification errors associated with the directional texture, and

(c) unlike normalisation it did not increase isotropic errors.

7.2. Conclusions

This thesis has used theory, simulation and laboratory experiment, to investigate the effect of changes in illuminant direction on image texture. It has been shown that variation in illuminant tilt can alter the directional properties of image texture, while variation in illuminant slant has been shown to effect a change in image variance. Both of these effects have been shown to affect the output of three sets of texture measures and hence also to significantly reduce the accuracy of classifiers employing these feature sets. To the author's knowledge the above points have not been explicitly addressed within texture classification research before.

Normalisation of images was shown to reduce variations due to changes in slant, but this was bought at the cost of reduced separation between class means of the test textures, and classification errors were not significantly reduced. Normalisation also reduced the effect of changes in tilt on images of the directional test texture. In this case classification errors associated with directional texture were reduced, whereas those associated with some of the isotropic textures increased.

A frequency domain model due to Kube and Pentland of image texture [Kube88] has, after being modified to take into account empirical observations, been used to develop a set of tilt compensation filters. Application of these filters to images of the test textures reduced the errors associated with the directional texture. Unlike normalisation it has not increased errors associated with the isotropic test textures. Neither has it reduced them. However, examination of the tilt responses suggest that there were few tilt induced isotropic errors to compensate for. In addition the reduced tilt sensitivities of tilt compensated features, when applied to isotropic textures, suggests that this scheme also has potential to improve the classification accuracy of isotropic textures.