EVALUATING SURFACE TEXTURE PREDICTION WHEN SEEN FROM DIFFERENT DISTANCES

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Abstract

The purpose of this work is to analyse what happens to the surface texture information when seen from different distances. 4-source Colour Photometric Stereo, which provides the surface shape and colour information, is used to predict how a surface looks like when changing the distance of the camera. Fifteen real sets of images captured at three different distances A, B, and C are used to perform an exhaustive evaluation of predictions from distance A and B, to longer distance C. Different error measures have been used in order to evaluate the accuracy of the surface shape and the image predictions.

Key words: Image processing, Texture analysis, Surface texture, Surface roughness, Colour photometric stereo.

1. INTRODUCTION

The 2-dimensional texture in the image, the *image* texture, is produced by the imaging geometry and variation in both surface reflectance and surface relief. The latter two constitute the *surface* texture, which give us the variation of the physical and geometric properties of the imaged surface. While the reflectance properties are intrinsic to the surface, the surface relief produces a pattern of shadings that depends strongly on the direction of the illumination [1]. Thus, the *image* texture created by a 3D *surface* texture changes drastically with the imaging geometry.

This paper uses *Colour Photometric Stereo* (CPS), as described in [2], to compute the detailed shape and colour of a rough surface when seen by a camera at the zenith of the surface. Photometric stereo is based on the fact that image intensities depend on the surface orientation and its reflectance. Hence, if several images are taken from the same viewing position but with different lighting directions, variation of pixel intensities in these images will be due to changes in the relative positions of the illuminant and the surface [3]. This constraint permits us to calculate the normal vectors, which represent the surface orientation of any point on the surface, and the reflectance factor or albedo, which describes the reflection properties of the surface. From this photometric information we are able to generate new images imaged under different directions of illuminations than those under which the images of the photometric sets were imaged.

In the last few years photometric stereo have been used in a large number of applications. For example surface texture analysis to perform illuminant invariant texture classification [4,5], and surface shape recovering with the aim to develop industrial vision-based inspection systems [6,7].

The goal of this paper is more specific since we perform an evaluation of the surface texture information obtained by the surface prediction framework proposed in [8]. This prediction framework enables the possibility to predict images of the same surface texture seen from different distances and under different directions of illuminations, as well as to predict the surface shape information. Fifteen real sets of images captured at three different distances A, B, and C are used to perform an exhaustive evaluation of predictions from distance A and B, to longer distance C. We evaluate the surface shape predictions and also the image predictions, providing an overall quantitative assessment over all fifteen textures using different error measures.

The rest of this paper is organised as follows. In section 2, the prediction framework is briefly explained. In section 3, we evaluate the predictions on fifteen real images. Finally, the work ends with conclusions.

2. PREDICTION PROCESS

The main objective of the prediction process is to understand what happens with the surface texture information if the distance of the camera is changed. In other words, what will the normal vectors and the image intensities be if the distance of the camera is changed leading to a new image in which every pixel is the union of several old pixels? This question is answered by deriving the relationship between the normal vectors and the image intensities when they are calculated in different image resolutions. In [8] we presented the prediction framework based on the 4-source colour photometric stereo. More specifically, two methods for predicting how a surface texture appears when seen from longer distances are presented. The first one analyses the direct relationship between image texture information (image intensities) under two different resolutions. This leads to *direct image prediction*. The second predicts first how the surface itself would be approximated in a lower resolution from the original one and then, from this lower resolution, it predicts the image it would create. This leads to *image prediction via surface prediction*. We will refer to this method as *surface prediction* for short. In Figure 1 both prediction methods are illustrated.

In previous works we analysed the abilities of the prediction methods presented in [8] in order to predict the surface/image information when seen from a longer distance. We concluded that the *image prediction* method, which predicts directly the pixel intensities, gives in general smaller errors in the image. We also observed that most of the error can be accounted for as being produced by the photometric stereo technique and not by the step dealing with the distance change. In terms of surface shape prediction, we concluded that the *surface prediction* method provides the best shape estimation. Moreover, we observed that in general surface roughness has an important influence in the accuracy of the surface shape predictions. For rougher surfaces the error of the predictions was increased.

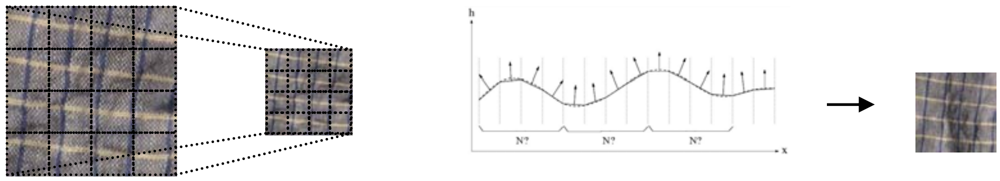

Figure 1. Image prediction framework. (a) Direct image prediction method. (b) Surface prediction method.

However, we have not evaluated the effect of predicting textures under different camera distances. Therefore, the main goal of the experiments presented in this paper is to analyse the effect of using two different resolutions in the original sets in order to perform the same prediction when seen at a longer distance, as well as to analyse the effect of using different distances in the *image prediction* and *surface prediction* methods.

3. EXPERIMENTAL RESULTS

Fifteen physical texture samples were used throughout the experimental trials presented in this work. For each texture a photometric set composed by 4 images each was available. All the photometric stereo sets were constructed by 4 images illuminated at a slant angle of 55º and with 4 different tilt angles 0º, 90º, 180º and 270º. As well as of the 4 images used in the photometric sets, different images for each surface were captured for testing using 12 illuminant tilt angles between 0º and 360º incremented in steps of 30º. All surfaces were illuminated at a slant angle of 55º.

Moreover, in order to perform all experimental trials, two different photometric sets for each surface were obtained from two longer distances, without varying the lights or the object position. We shall refer to the photometric sets taken from distance A, B, and C as photometric sets A, B, and C respectively. Figure 2 shows 3 images of two textures seen from distances A, B, and C. The photometric sets allow us to make the predictions from distance A and B to distance C, which we shall refer as predictions AC and BC. Moreover, as well as of the images of the photometric sets, another set of test images for each surface were captured from the longer distances B and C, using the same illuminant tilt angles than those captured from distance A. We shall refer to these test images at distance A, B, and C as tA, tB, and tC respectively. Finally, we shall refer to the images generated by the photometric sets at distance A, B, and C as AA, BB, and CC respectively. In our image database we include two major groups of surface textures: one group with a wide variety of relative smooth surfaces which may be grouped into *isotropic surfaces* or *directional surfaces*, an the other one with a variety of very rough surfaces for which the assumption on which photometric stereo is based (i.e. relatively smooth surfaces, low roughness) is violated.

Figure 2. Three images of two surface textures seen from distances A, B, and C, respectively.

A description of a surface can be made from different ways. For example a single parameter may be sufficient to characterise a surface for some purposes. This is the case of the *absolute average slope ratio* (AASR) which provides an easy way to characterise the degree of roughness of a given surface texture. For other purposes in which a major degree of description is required, an statistical model such as the histogram of the gradient variation can provide a more visual comprehension of the surface's characteristics. In this work we have opted to use both descriptors, the estimated probability density functions for the surface partial derivatives p and q, and the AASR parameter, in order to characterise the surface shape and roughness of each texture.

The experiments we have performed have as purpose to check two aspects: 1) to check the accuracy of surface shape prediction using photometric sets captured at distance A and B to predict the surface as it will appear at the resolution at distance C and compare the predictions which the surface reconstructed from a photometric set captured at distance C and with the same light orientations as for the set at distance A and B. 2) To check the accuracy of image prediction using a photometric sets captured at distance A and B to predict the image as it will appear at the resolution at distance C. The predictions will be compared with real images captured at distance C and also with images produced from a photometric set captured at distance C.

3.1 Accuracy of surface shape prediction

The goal of this experiment is to perform an evaluation of the *surface shape prediction* method, comparing the predicted gradient vectors AC and BC with those obtained using the original photometric set at distance C.

The PDF of p and q are used in order to compare the surface shape information. Analysing all the PDFs we observe that results obtained by the prediction AC fit better the original PDFs distributions. On the other hand, we also observe that surface shape information extracted from distance B introduces more error in the predicted gradient vectors. In general, the gradient values are smaller than those obtained from the distance A. In table 1 we confirm this conclusion providing an overall quantitative assesment over all these histograms comparisons. We have computed over all textures the average MSE of each histogram and its standard deviation. Moreover, we have also included the average MSE per pixel of the gradient components p and q. In both cases better results are obtained when the prediction is obtained from distance A. The reason of these results can be found in the major resolution of the images at distance A and therefore in the best gradient vector predictions. Note that with the prediction AC more surface patches are used to compute the normal vector corresponding to the surface path at distance C. On the other hand, the information predicted from distance B is less accurate since less normal vectors at distance B are used to predict the corresponding ona at longer distance C.

Table 1. Overall quantitative assessment over all 15 textures of shape predictions AC and BC. Two quantitative measures: (1) the average MSE of the PDFs and its standard deviation. (2) the average MSE per pixel of gradient components p and q and its standard deviation.

		p		q	
	Pre.	Avg.	Std.	Avg.	Std.
PDF error	AC	0.0008	0.0005	0.0006	0.0002
	BC	0.0010	0.0004	0.0011	0.0006
Pixel error	AC	0.0794	0.0525	0.0873	0.0449
	BC	0.1130	0.0606	0.1343	0.0638

As it has been described above, the *absolute average slope ratio* (AASR) provides another way to characterise with a single parameter the degree of roughness of a given surface texture. We have also used this ratio to evaluate our surface shape predictions. We have compared the AASR of our predictions AC and BC. Table 2 gives an overall quantitative assessment over all textures computing the average MSE of the AASR parameter obtained using both predictions. Note that the values obtained by the surface predictions AC are again better than those obtained by the predictions BC.

Table 2. Overall quantitative assessment over all 15 textures of the AASR parameter. Average MSE and its standard deviation for prediction AC and BC.

Prediction	Avg.	Std.
AC	0.0091	0.0078
BC	0.0263	0.0114

As a result of this experiment we conclude that the prediction AC, which has a larger distance prediction, provides us better shape estimation than the prediction BC. Moreover, we observe that surface roughness has an important influence in the accuracy of the surface shape predictions. For rougher surfaces the error of the predictions is increased.

3.2 Accuracy of image prediction

This experiment has the goal to evaluate the accuracy of the *direct image prediction* method, using a photometric set captured at distance A and B, to predict how an image will appear at the resolution at distance C. Therefore, we have performed a comparison between the test images tC and the predicted images obtained from the distances A and B. To quantify the difference between a captured colour image and a predicted one we use the mean square error of colour differences computed over all pixels. In order to compute the colour difference between the predicted and true RGB values for a pixel we use the Euclidean metric in conjunction with the Luv colour space. This way the estimated error in colour will reflect the perceived error in colour, since Luv space is assumed to be perceptually uniform.

Table 3. Overall quantitative assessment for each prediction over all 15 textures and all tilt angles. Average MSE and its standard deviation for the colour.

Overall assessmentiction	Avg.	Std.
tC vs CC	10.4412	3.5115
tC vs AC	11.4239	3.3770
tC vs BC	13.2937	3.9568

Observing these results obtained over the fifteen textures we conclude that in almost all the cases the performance of both predictions is similar, although the predictions AC give in general smaller errors in the image. In table 3 we give an overall quantitative assessment for each prediction by computing the average MSE and its standard deviation over all textures and all tilt angles which confirm this conclusion. It is also important to note that the major error is produced by the photometric stereo technique and not by the inclusion of the distance prediction. Moreover, we have observed that surface roughness has an influence in the accuracy of the image predictions. For rougher surfaces the error of the prediction is increased.

4. CONCLUSIONS

We evaluated a prediction framework for predicting surface texture information when seen from different distances. The 4-source CPS has been used in order to obtain the reflectance and the surface shape information of the surface. The proposed framework allows us to predict the surface shape information as well as the image intensities under different resolutions. It is based on the assumption of Lambertian surfaces, but it can easily be generalised to other types of surface.

The methods have been exhaustively evaluated using fifteen real sets of images captured from three different distances (A, B, and C), demonstrating the capability to predict the surface texture information when seen from a longer distance. We concluded that better predictions are those obtained from the information extracted at closest distance. Different error measures have been used in order to evaluate the surface shape and the image predictions.

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