

ESTIMATION OF RADIOMETRIC PARAMETERS FOR A REALISTIC RENDERING OF 3D MODELS

Federico Pedersini, Luca Piccarreta, Augusto Sarti, Stefano Tubaro

Dip. di Elettronica e Informazione (DEI), Politecnico di Milano
Piazza L. Da Vinci 32, 20133 Milano, Italy
E-mail: pedersin/piccarre/sarti/tubaro@elet.polimi.it

ABSTRACT

In order to obtain realistic results in the rendering of a 3D model, we need accurate information on both structure (shape) and radiometric properties (reflectivity) of its surfaces. In this paper, we approach the problem of correctly estimating the radiometric characteristics of an imaged surface through the analysis of several of its views. The images are acquired with one or more CCD cameras that move around the object, and the 3D model is assumed available (it can be constructed from the available images). The adopted reflectivity model is non-Lambertian as it takes into account both the diffuse lobe and the specular lobe. The method implements a robust technique which is able to estimate the reflectivity parameters of the object's surfaces even in the presence of modeling imperfections and/or when the relative camera-object position and orientation are only approximately known.

1. INTRODUCTION

In the past few years, several methods have been proposed for modeling a 3D scene from a set of its images. In [1], for example, the object to be modeled rotates on a turntable while a fixed calibrated CCD camera acquires a sequence of its views. A mesh of triangles that approximates the object's 3D shape is then created through the analysis of the occluding contours (silhouettes) on all the available images [2]. If the topology of the imaged object is not too complex, this classical volumetric intersection approach returns a complete 3D model. However, in order to be able to synthesize a generic virtual view of it, this model needs to be textured using all the available images. This raises the problem of how to account for mismatches between corresponding texture profiles in difference images and, ultimately, how to merge them in a single 3D model. In principle, in order to overcome such difficulties, besides the geometrical properties of the imaged surfaces, it is

necessary to estimate its radiometric properties and an illumination model [3].

A number of methods are available in the literature, which address the problem of texture mapping from multiple views. Such solutions attempt the estimation of some radiometric properties through the analysis of the surface radiance under different viewing and/or illumination conditions [4]. Unfortunately, we found that such techniques, though theoretically interesting, are very sensitive to the accuracy of the available information, and are unsuitable for many applications. In particular, they require a very accurate knowledge of both object shape and camera parameters for each one of the available images. In particular, it is necessary to know very precisely where a 3D point is projected on all the images and what the orientation of the tangent plane to all surface points is like. This is the reason why most of the algorithms of this category estimate the surface normal along with the local radiometric properties [5] (shape from shading). In our case, we assumed that the acquisition conditions and the viewpoints were only approximately known, therefore the matching of stereo-corresponding elements on the images was only possible up to a limited extent.

A simple but very often effective approach consists of associating the textural information (as provided by one of the available images) to each triangle of the surface mesh [1]. In particular, the camera whose optical axis is most perpendicular to the triangle is preferred; while the luminance information is taken as the only local radiometric information available. The luminance is, in fact, assumed as being proportional to the albedo (assuming a Lambertian model for the description of the surface radiance).

In order to obtain realistic synthetic views using the above approach, the illumination of the scene needs to be kept as diffuse and uniform as possible during the acquisition session. Only in this case, in fact, may the luminance be considered as representative of the intrinsic radiometric properties of the surface. When

such conditions are not perfectly met, however, several problems arise. For example, inconsistency between the rendered relative brightness of different surface regions becomes apparent. In fact, regions with different orientation but similar radiometric properties will not be consistently rendered, due to the different illumination conditions that characterize the available image. Furthermore, brightness discontinuities at the boundaries of neighboring triangles whose texture is extracted from different images will become visible.

In order to avoid such problems, a number of methods have been developed in the literature, many of which consist of some postprocessing operation for improving the visual quality of the global texturing. In [1], for example, a strategy for selecting the images from which to extract textural information for each triangle of the surface mesh is proposed along with a method for performing local texture filtering near the boundaries between triangles. This solution is able to produce results of significant quality and pleasantness. The approach that we propose in this paper is similar to that one, in that it performs texture mapping from the most suitable view among the available ones, but it introduces some significant extensions and generalizations.

Triangle-based radiometric estimation techniques are applied to assign each triangle of the surface mesh of the object model both textural and radiometric information. This allows us to synthesize realistic and pleasant virtual views of the object. Although the approach that we developed is here applied only to grayscale images, the procedure can be quite straightforwardly extended to color images, provided that the spectrum of the light used during the acquisition session is known. Moreover, we typically use several trinocular views acquired with three CCD cameras placed at the vertices of a triangle, with verging optical axes. Although this does not change the texture mapping strategy, the use of more than one camera instead of a single one has the advantage of a more uniform distribution of the views and it enables to use efficient stereo algorithms for the refinement of the 3D model obtained through a simple analysis of the occluding contours. Finally, it enables the estimation of the relative motion between object and camera system without the need of expensive positioning devices. Because of this choice, our texture mapping strategy includes also a compensation of the different responsiveness of the various cameras.

2. THE PROPOSED APPROACH

Each triangle of the surface mesh is associated to different triangular regions on the available images. If the triangle surface is sufficiently small, then within such

region the image luminance will be uniform, and it will vary from image to image depending on the mutual orientation between light source(s), surface element and viewpoint. The set of all corresponding triangular regions can be seen as a collection of different projection instances of the same surface patch, and can be used for estimating its radiometric properties. On the other hand, if the object exhibits very detailed textural information, the uniformity of the luminance profile within the triangular patches would only be guaranteed by a surface mesh made of a very large number of triangles. As the computational load is a critical aspect of rendering applications, the resolution of the mesh of triangles can only be decided upon the complexity of the shape of the object to be modeled, therefore we cannot expect the texture to be uniform within triangular patches. As a consequence, using the luminance profile of the whole triangle in order to estimate the local radiometric properties of the surface mesh could lead to undesired results as this would imply an averaging of the surface parameters. An immediate consequence of this choice would be a very visible blurring of the textural information.

In order to avoid these problems, the radiometric estimation had better be performed over regions that are much smaller than the triangles. Due to the unavoidable inaccuracy that the 3D mesh and camera parameters are affected by, this operation could lead to meaningless results. When the 3D model is not accurate enough, the backprojection of different images onto the surface turns out to be inconsistent. In fact, the texture mappings will appear as slightly offset or distorted with respect to one another. This would result in an undesired doubling of textural features, as shown in Fig. 1. Moreover, we should not forget that the models that describe the scene are only an approximation of the reality, due to the intrinsic modeling and estimation accuracy and to the need to keeping the algorithms as computationally efficient as possible.

On the other hand, we found that the MSE estimation of the radiometric properties over the whole triangle constitutes a good estimate of the DC component of its albedo (which is the only parameter that describes the surface properties in the Lambertian case). When considering a single view, this requires constant illumination conditions over the whole triangle. We can assume that the viewing and illumination angles are constant, as the distance between cameras and shape is usually much larger than the average size of the triangles. Moreover, the size of a triangle is usually related to the local curvature of the object's surface, therefore the variation of the surface's normal can be assumed as modest within the region that corresponds to that

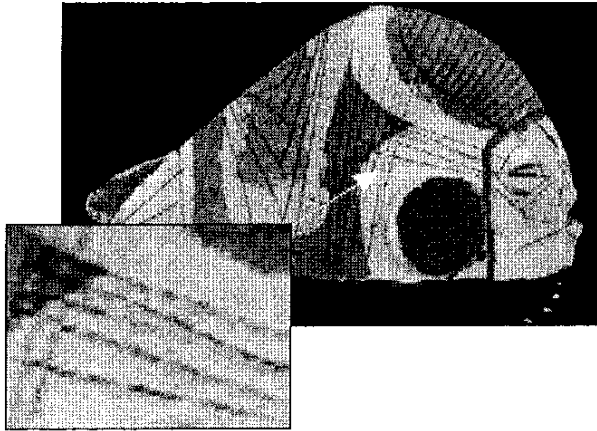


Figure 1: Loss of visual quality due to an excessive spatial resolution of the estimation process: the rendered view (enlargement) is here compared with the original view.

triangle. Furthermore, a way of using the radiometric estimation, while preserving a good spatial resolution, is to separately process the AC and the DC components of the luminance profile within each triangular patch. The DC component is used for estimating the radiometric model (illumination and reflectivity), while the AC component is kept as a candidate for extracting the local textural information (albedo). Among all the available AC components relative to the same surface triangle, the one corresponding to the most orthogonal viewing direction (triangular patch of maximum area) is used for generating the textural information. The generation of a virtual view is thus performed by mapping onto each surface triangle the AC component extracted from the most orthogonal view, combined with the DC component computed with the estimated radiometric model. We will see that the choice of separately treating the DC and the AC components of the luminance profile, although heuristic, leads to significant results with a modest computation load.

The estimation of the radiometric model (illumination and reflectivity) is performed using a robust method [6], which leads to a correct estimation even in the presence of surface modeling imperfections, camera calibration inaccuracies and illumination modeling limitations (we modeled the illumination field as a diffuse plus directional lighting). In order to account for differences between CCD sensors, gain and offset parameters are estimated for each one of the employed cameras.

We modeled the non-lambertian surface reflectivity with a Torrance-Sparrow radiometric model [7], therefore only diffuse and specular lobes have been accounted

for, while the specular spike has not been included, as it only occurs with mirror-like surfaces. Unfortunately, due to shape modeling imperfections, camera calibration inaccuracies and illumination modeling limits [8], the estimation of the parameters of the specular lobe is most often critical. Consequently, it is usually safer to estimate only the diffused lobe. Specular reflections can be artificially added during the rendering phase [3].

As a final remark, the view that is selected for generating the AC component of the textural information can frequently change from triangle to triangle of the surface mesh. This fact can generate artifacts on the synthesized virtual views. In order to limit the impact of this problem on the overall rendering quality, we developed an efficient regularization procedure that tends to favor the selection of the same camera for neighboring triangle patches.

3. EXPERIMENTAL RESULTS

In order to test the proposed method, we performed a number of experiments using several synthetic and real images. The first test concerned texture mapping on the 3D model of a terra-cotta fish (see Fig. 1), obtained through volumetric intersection [1, 2] from 21 images of standard TV-resolution.

As we can see in Fig. 2, our approach tends to regularize the assignment of texture to the triangles, thus minimizing the length of the region borders. Fig. 3 shows how the estimated radiometric information improves the texture mapping results.

The second test concerned the texture mapping onto a 3D model of a human face (Fig. 4, obtained from three calibrated views using an area matching method [9]. Figs. 5 and 6 shows the impact of radiometric compensation on the quality of the texture mapping.

As far as the required computation load is concerned, the radiometric estimation for the terra-cotta fish (using a mesh model with about 5000 triangles) requires approx. 250 sec. on a 200 Mhz Pentium Pro PC.

One key feature of the proposed algorithm turned out to be its robustness to incorrect assumptions on the radiometric and illumination models. In order to test the algorithm on this problem, we generated a set of 21 synthetic images of a strongly non-lambertian sphere, rendered under a highly directional light. Even, in these conditions, we adopt a diffused illumination model (by eliminating the estimated directional component), the virtual views turned out to be surprisingly good. We also found that, using a lambertian reflection model, the robust approach was able to efficiently detect specular reflections and treat the corresponding

triangles as outliers.

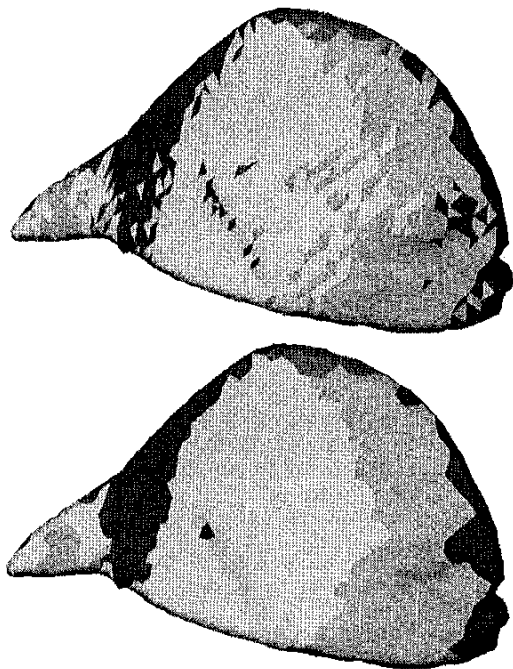


Figure 2: The effect of regularization on the assignment of texture to the triangles: each color represents a different camera.

4. CONCLUSIONS

Future related activity will focus on more effective methods of estimation of the specular lobe of the radiometric model. In order to make the radiometric estimation more robust, a pre-segmentation of the triangle mesh into “homogeneous” regions will be carried out and the characteristics of specular lobe will be estimated region-wise rather than triangle-wise.

5. REFERENCES

[1] W. Niem, H. Broszio, “Mapping Texture from Multiple Camera Views onto 3D-Object Models for Computer Animation”. *Intl. Workshop on Stereoscopic and 3D Imaging*, Sept. 6-8, 1995, Santorini, Greece.

[2] J. Yu Zheng, “Acquiring 3D models from sequences of contours”, *IEEE Tr. PAMI*, Vol. 16, No. 2, pp. 163-177, 1994.

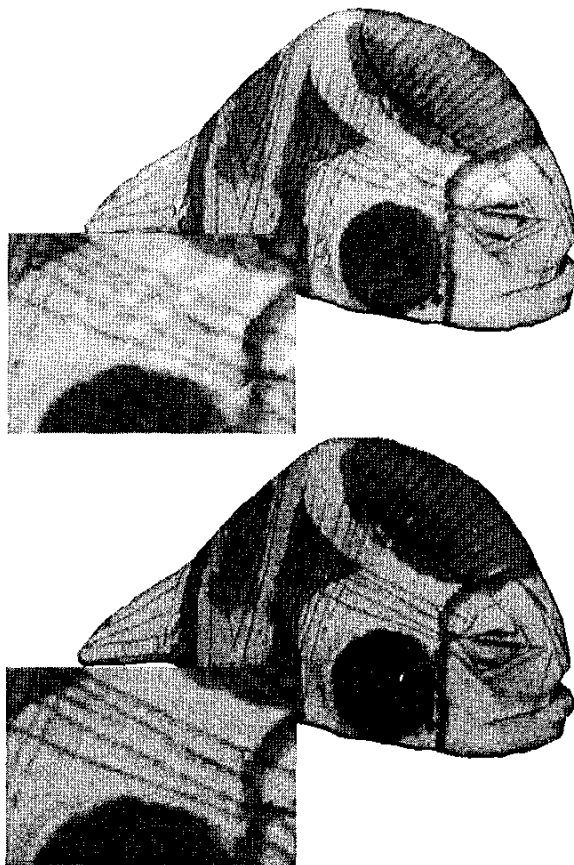


Figure 3: The effect of the algorithms described: the discontinuities are much less visible.

[3] J. Foley, J. Hughes, A. Van Dam, S. Feiner, *Computer Graphics: Principles and Practice*, 2nd Ed., Addison Wesley, 1990.

[4] G. Kay, T. Caally: “Inverting an Illumination Model from range and Intensity Maps”. *CVGIP: Image Understanding*, Vol. 59, No. 2, p. 183-201, 1994.

[5] H.D. Tagarc, P. DeFiguereido: “Simultaneous Estimation of Shape and Reflectance Map from Photometric Stereo”, *CVGIP: Image Understanding*, Vol. 55, No. 3, p. 275-286, 1992.

[6] R.G. Staudte, S.J. Sheather, “Robust Estimation and Testing”, Wiley 1990.

[7] K.E. Torrance, E.M. Sparrow, “Theory of off-specular reflection from roughened surfaces”, *J. Opt. Soc. of Am.*, No. 57, p. 1105-1114, 1967.

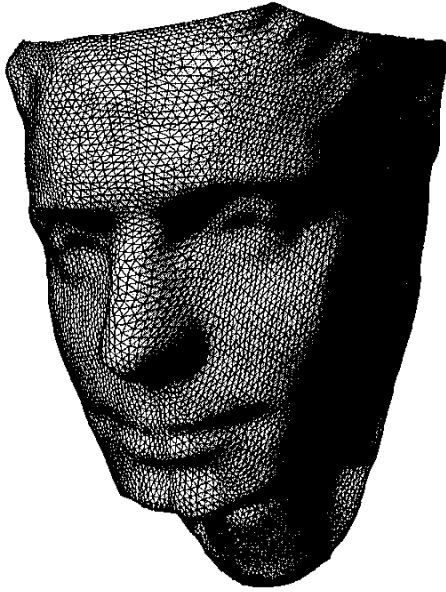


Figure 4: 3D model of a face, obtained through area matching.

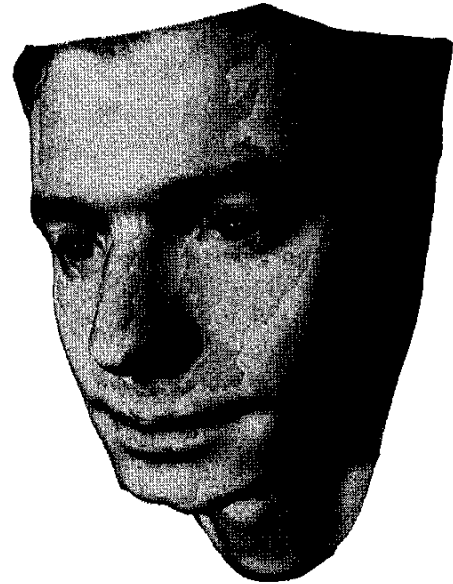


Figure 5: Texture mapping results without radiometric compensation.

- [8] Y. Sato, K. Ikeuchi, "Reflectance Analysis for 3D Computer Graphics Model Generations", *Graphical Models and Image Processing*, Vo. 58, Sept. 1996, p. 437-451.
- [9] P. Pigazzini, F. Pedersini, A. Sarti, S. Tubaro, "3D Area Matching with Arbitrary Multiview Geometry". *Signal Processing: Image Communications*, Vol. 14, No. 1-2, p. 71-94, 1998.



Figure 6: Texture mapping results with radiometric compensation.