TEXTURE MAPPING OF FLAT-LIKE 3D MODELS

F. Uccheddu[a], A. Del Mastio[a], F. Remondino[b], A. Pelagotti[c] and V. Cappellini[a]

[a] Dept. of Electronics and Telecommunications
University of Florence
via Santa Marta 3, 50139,
Florence, Italy

[b] B. Kessler Foundation (FBK)
Centre for Scientific & Technological Research (IRST)
Optical Sensors and Interfaces (SOI) - 3D Optical Metrology Group
via Sommarive 18, 38050,
Trento, Italy

[c] ART-TEST s.n.c.
c/o Incubatore d'impresa, Polo Scientifico e Tecnologico
via Giuntini 13, 56023,
Navacchio (PI), Italy

ABSTRACT

Recently, thanks to the diffusion of scanning devices and the availability of powerful 3D modeling software, as well as to the improvements in the automation of the image-based modeling approach, it is foreseen that 3D models will become more and more ubiquitous in several research fields. However, 3D models obtained by these technologies often are lacking for a suitable photorealistic appearance, due to the low quality generated texture, or to the complete absence of it. A post-processing texture mapping is often used to obtain highly realistic models, through an accurate manual alignment of the model and the related texture. In this work, we propose an automatic approach for mapping the texture on flat-like 3D models, in which the depth component is smaller compared to the object's height and width, such as in bass-relieves, coins, paintings or facades. The method relies on the evaluation from the model geometry of a depth map, used to align the texture image. The results show the effectiveness of the proposed method.

Index Terms— texture mapping, 3D, mesh, registration, mutual information

1. INTRODUCTION

3D models are being readily used in a variety of applications including mechanical engineering simulations, virtual museums and archaeological sites reproduction for Cultural Heritage, scientific visualizations, entertainment industries for movies and video-games and so on. In order to increase the visual appearance and the realism of 3D models, a texture is joint to the model itself; this texture can be a uniform or a faded color, different colors or, more frequently, an image (such as a photo) of the object. Several methods for the texturing of a 3D model have been proposed in literature. Very frequently, they suffer from the need of manually selecting a number of common points between the model and the texture, so that a DLT registration method can be applied.

In this paper, we propose a method for the texturing of a particular kind of 3D models, we called flat-like 3D models: they are models whose extension along the depth direction (say z) is significantly lower with respect to the extension along the other axis (say x and y). For example, think to paintings or low-relieves, whose depth is often several times lower than their height and width. The algorithm is based on the computation of the depth map, which is the grey-scale representation of the depth of the model. Since it is computed starting from the geometry of the model itself, the depth map preserves the relation between its pixels and the vertexes of the model. Thus, each photo of the object which is correctly aligned with the depth map can be used as a texture for the model, with no need of a further manual alignment. The proposed method thus moves the difficulty of the manual selection of common points between the texture and the model, up to an automatic registration between the texture image and the computed depth map. This technique is also suitable for texturing 3D models using image data coming from different sensors, such as a Infrared or Visible Induced Fluorescence. This can help in obtaining an augmented visualization of the heritage, showing details which can be useful for the work of restorers and curators or allowing quantitative analysis of the object.

In the following, in section 2 some basic concepts concerning 3D models and their representation is given; in section 3, the proposed method is presented, with particular reference to the depth map image generation and to the registration task; in section 4, some experimental results are given, to prove the effectiveness of the proposed method. Some concluding remarks given in section 5 close the dissertation.

2. 3D MODELLING AND TEXTURE MAPPING

There are different methods to produce digital 3D models and usually a technique is selected according to the project requirements and budget. A very common technique is based on image data while other approaches use range sensors like laser scanners. Image-based procedures [16] need a mathematical model to derive the 3D object information starting from the 2D image information while range (or active) sensors [17] are able to provide directly the 3D coordinates of an object of interest. Generally, the measured 3D points (point clouds) are converted into a polygonal mesh as polygons are the most flexible way to accurately represent the results of 3D measurements, providing an optimal surface description. After the creation of a mesh, the results are visualized as wireframe or shaded or textured mode. In many applications with large volumes of points, the recovered 3D data can be visualized simply by drawing all the samples, maybe with a point-based rendering approach [6] able to reduce the CPU and graphic card problems. However, for some objects, particularly those with sparse point clouds, this technique does not give an accurate representation and does not provide realistic visualization. Moreover the visualization of a 3D model is often the only product of interest for the external world and remains the only possible contact with the model. Therefore a photo-realistic and accurate visualization is often required and extremely important. For the texture mapping of a surface model, (colour) image information is mapped onto the reconstructed 3D geometry. A common approach requires the knowledge of the interior and exterior camera parameters and computes the corresponding image coordinates for each vertex of the polygonal surface model. Then the colour values within the projected triangle are attached to the surface. Although this seems straightforward, there are many factors affecting the photo-realism of a textured 3D model:

Radiometric image distortion: this effect comes from the use of different images acquired from different positions or with different cameras or under different lighting conditions. Therefore, in the 3D textured model, discontinuities and artefacts are present along the edges of adjacent triangles textured using different images. To avoid this, several techniques, such as blending methods based on weighted functions, can be used [7] [11][10].

Geometric scene distortion: this kind of error is generated from an incorrect camera calibration or an imprecise image registration (i.e. incorrect alignment between texture and 3D model) or errors in the mesh generation. Any of these sources of error may prevent the preservation of detailed content such as straight edges or major discontinuities in the surface. Accurate bundle adjustment, precise image registration and polygon refinement must be employed to reduce or minimize these geometric errors. Weinhaus and Devich [12] gave a detailed account of the geometric corrections that must be applied to remove distortions resulting from the transformation of the texture from the image plane to the triangle plane.

Dynamic range of the image: digital images often have a low dynamic range. Therefore bright areas are generally saturated while dark parts contain low signal to noise (S/N) ratio. To overcome these problems high dynamic range (HDR) images should be generated [8] for more photo-realistic texturing.

Object occlusions: extraneous static or moving objects such as pedestrians, cars, other monuments or trees, imaged in front of the modelled objects are obviously undesirable in the final result and should be as better as possible removed in the pre-processing step [14][13].

3. THE PROPOSED METHOD

The proposed method automatically generates the depth map image of the flat-like surface intrinsically creating a mapping between this image and the vertices of the model itself. The second step involve a mutual information based registration between the depth map image and the to be mapped external image. In fig 1 the schema is depicted.

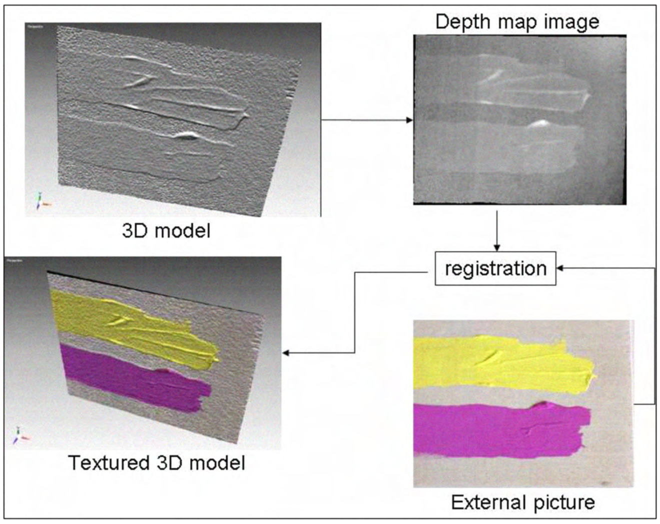

Fig. 1. Sketch of the proposed method. From the 3D model a depth map image is generated. This is automatically registered with an external image and the 3D model textured.

3.1. The depth map

A depth map is a two-dimensional array where the x and y distance information corresponds to the rows and columns of the array as in an ordinary image, and the corresponding depth readings (z values) are stored in the array's elements (pixels). From a depth map is possible to build a grey scale image in which the z information replaces the intensity information. Building a depth map image from the pure geometry of a 3D model (the x,y,z coordinates of its vertices), allows to keep all the exact correspondences between the 3D vertices and the values in the depth map. Given a 3D point of the model, from its coordinates $(x, y, z) \in R^3$ a couple $(i, j) \in R^2$ in the map is found. The 2D map dimensions from which the image will be extracted, depend on the 3D resolution: in order to associate one single intensity value in each pixel of the depth image, the "size" of each pixel must be such that, at most only one vertex falls in the pixel area, and the intensity to be normalized will be the following:

$$I(i,j) = \begin{cases} z & if \exists (x,y,z) \textit{in the model}: \lfloor x \rfloor = i, \lfloor y \rfloor = j \\ 0 & else \end{cases} \quad (1)$$

The last needed step for the depth image generation is the z-values normalization between 0 and 255.

The so generated depth map image is intrinsically mapped in to the model, so the first visual enhancement we could give to a 3D model is to build a texture from its depth image, or better, to use an other image of the model as a texture, by first registering it with the depth image.

3.2. Registration step

Image registration is the process that aligns points in one view of an object or scene with corresponding points belonging to a different view of the same subject; that is, registration aims to determine the correct displacement (that is a geometrical transformation including sub-pixel translation, rotation and scaling) to align two views of the same subject, which can be imaged at different times, from different viewpoints, by different sensors. Image registration is a fundamental step in many image processing and analysis tasks, in which gaining all the single data lead to a more complete information. For example, registration is a crucial step in remote sensing (dealing with multispectral images, mosaicing), in medicine (combining CT and NMR, monitoring of tumor growth), in computer vision (target localization), more recently in Cultural Heritage applications (multispectral analysis of pigments) [1, 2, 3].

In our work, we exploited an automatic registration technique[15] to align the range map and the texture images: since the computed depth map preserves the relationship of each pixel with the corresponding vertex of the 3D model, after the registration step such a connection is also maintained for the texture image. The registration technique is based on the computation of the Mutual Information, which is a similarity measure coming from the Information Theory. Roughly speaking, mutual information is a measure of how much information one image contains about another one. Accordingly to the MMI criterion (Maximization of Mutual Information), the correct alignment is caught when the Mutual Information assumes its maximum value [4].

Given two images X and Y related by the geometric transformation T_α, with parameters α such that the pixel p of X, whose intensity value is x, corresponds to the pixel $T_\alpha(p)$ of Y whose intensity value is y, their MI is given by:

$$I(X;Y) = \sum_{x,y} p_{XY}(x,y) \cdot \log_2 \frac{p_{XY}(x,y)}{p_X(x) \cdot p_Y(y)} \quad (2)$$

where $p_{XY}(x, y)$ is the joint distribution, $p_X(x)$ and $p_Y(y)$ the marginal ones. The correct alignment for two images is inferred for the transformation T_{α^*} for which:

$$\alpha^* = \arg\max_\alpha I(X;Y) \quad (3)$$

Estimations for the joint and marginal distributions are obtained by normalization of the joint histogram of the two images, which is in turn obtained by binning the intensity value pairs $X(p)$ and $Y(T_\alpha(p))$ for all the pixels and for the chosen transformation [4]:

$$\begin{aligned} p_{XY,\alpha}(x,y) &= \frac{h_\alpha(x,y)}{\sum_{x,y} h_\alpha(x,y)} \\ p_{X,\alpha}(x) &= \sum_y p_{XY,\alpha}(x,y) \\ p_{Y,\alpha}(y) &= \sum_x p_{XY,\alpha}(x,y) \end{aligned} \quad (4)$$

Given a general transformation, the pixel position $T_\alpha(p)$ will not coincide with a grid position; thus, interpolation of it is required when creating the joint histogram. Once estimated the optimal registration parameters α^*, the texture image can be correctly aligned to the depth map, thus inferring the connection between pixels of the texture and vertex of the 3D model.

4. EXPERIMENTAL RESULTS

To demonstrate the effectiveness of the proposed method, we generated different 3D models and afterwards texture them. The models are produced with photogrammetry or range sensors. The first example, reported in figure 2 and 3, shows a 3D model of a board produced with a triangulation-based laser scanner and where we applied two colored stripes.

The generated depth map of the model is registered with the MMI method and then projected onto the 3D geometry. The detail shown in figure 3 demonstrates that the alignment has been correctly performed, since the light area of the texture corresponds to the top of the paint stroke, as it actually is.

In figure 4 is shown a comparison between a low quality texture automatically generated by the laser scanner, and the

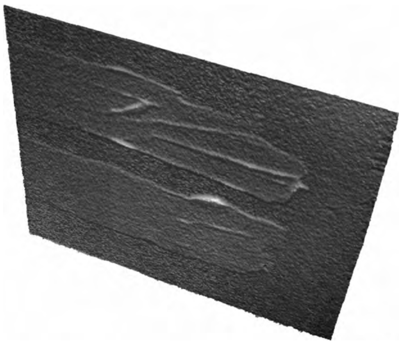

Fig. 2. Model of the test board textured with the depth map.

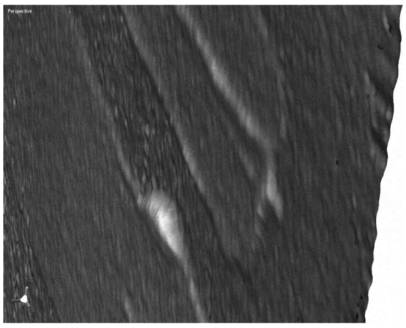

Fig. 3. Model of the test board textured with the depth map - detail.

model with an higher quality texture generated with our texture mapping system. It is clearly visible the more realistic appearance of the board.

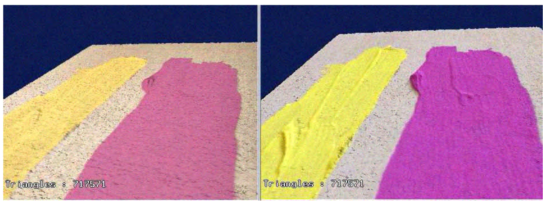

Fig. 4. Comparison between the acquired model (left) and the same after the proposed texture mapping (right).

The method has been also tested on a real painting, depicted in figure 5 (a). Figure 5 (b) depicts the generated depth map of the painting. The paint strokes and their thickness are clearly visible and this is useful for the registration step.

The method showed good performances also with other flat-like objects, such as bass-relieves or coins. In figure 6 an example of a coin is reported. Figure 7 depicts the computed depth map generated from the scanned 3D model: the relieves are clearly visible, varying from the dark (lower areas) to the white (upper areas). Once the photo of the coin has been correctly registered with the map, it is possible to accomplish the texture mapping, leading to the model depicted in figure 8.

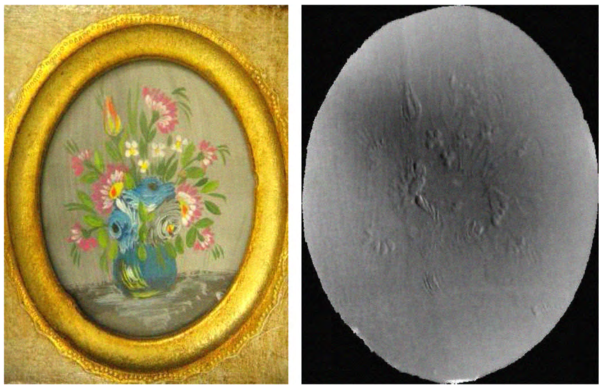

Fig. 5. Image of the painting.

Fig. 6. Image of a painting and derived depth map from the measured 3D model. The map clearly shows the thickness of the strokes, features used in the registration steps.

The employed 3D scanner acquired also a low-resolution texture. Figure 9 shows a closer view of a detail of the textured model, comparing the rough texture coming from the scanner with the textured version realized employing an external high-resolution image and the proposed method.

Finally, in figure 10 we show the results obtained by joining a Visible Induced Fluorescence image to the 3D geometry of a painting. Visible Induced Fluorescence is an investigation technique, able to highlight some features of paintings, such as restored areas which often are not distinguished to the naked eye. Mapping the fluorescence image as a texture for the model leads to an improved visualization of the painting itself, gaining the information the fluorescence bring to the geometrical information of the 3D model, and letting restorers to have an accurate landmark of restored areas.

5. CONCLUSIONS

In this paper, an automatic texture mapping technique has been presented. The method is based on the computation of

Fig. 7. Generated depth map of the coin.

Fig. 8. Textured model of the coin.

the depth map from a model, which is a two-dimensional array where the x and y-coordinates of the model corresponds to rows and columns of the array as an ordinary image, and the z-coordinates (depth) are stored in the corresponding array elements. The depth map can be regarded as a grey scale image, in which the grey levels keep into account the depth information of the model. The depth map maintains intrinsically the connection with the vertexes of the 3D model; thus, simply registering a photo of the object with the depth map, it is possible to accomplish an accurate texture mapping of the model itself.

The proposed method overcomes the need of a manual detection of common points in the model and in the texture image; that is, the process is completely automated and the accuracy depends on the registration algorithm, while in the manual detection the correctness of the mapping is very subjective.

The method has been developed for flat-like models, thus is applicable when dealing with objects such as paintings, coins, or in general objects whose depth is extremely lower with respect to its height and width. As mentioned above, the

Fig. 9. Detail of the acquired coin model (left) compared with the model textured by the proposed method using an external high-resolution image (right).

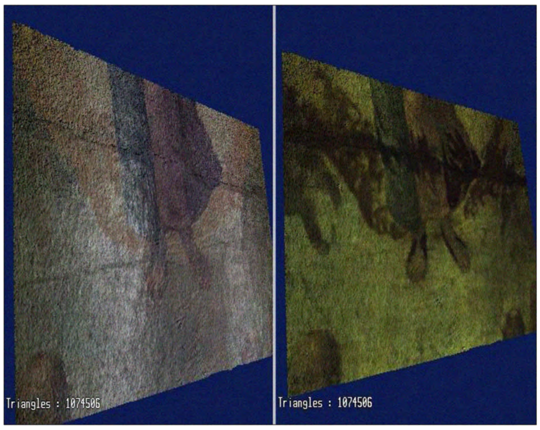

Fig. 10. Example of a fluorescence image registered and mapped onto a 3D model of a paint.

accuracy depends on the registration step; thus, it becomes a very crucial task in the whole method.

The proposed texture mapping algorithm can be extended to different kinds of objects, such as revolution solids: in this case, the depth map will be computed as a difference between the actual z-coordinate and the z-coordinate of an ideal solid similar to it. Works are in progress to extend the proposed method in such a case.

6. ACKNOWLEDGMENTS

The authors would like to thank Riccardo Vannetti, for helping them in developing this work during his degree thesis [5].

7. REFERENCES

[1] B. Zitovà, and J. Flusser, "Image registration methods: A survey," *Image and Vision Computing*, vol. 21, pp. 977–1000, June 2003.

[2] J. Michael Fitzpatrick, Derek L.G. Hill, and Calvin R. Maurer Jr., *Handbook of Medical Imaging - Volume 2,*

Medical Image Processing and Analysis - ch. 8, Image Registration. Address: SPIE PRESS, Bellingham, Washington, 2000.

[3] V. Cappellini, A. Del Mastio, A. Pelagotti and A. Piva, "An automated registration technique for cultural heritage images" in *8th International Conference on Non Destructive Investigations and Micronalysis for the Diagnostics and Conservation of the Cultural and Environmental Heritage*, Lecce (Italy), May 2005 .

[4] F. Maes, A. Collignon, D. Vandermeulen, G. Marchal, and P. Suetens, "Multimodality image registration by maximization of mutual information," *IEEE Trans. Medical Imaging*, vol. 16, pp. 187–198, 1997.

[5] R. Vannetti, "Tecnica automatica di mappatura di immagini ad alta risoluzione per modelli 3D di opere pittoriche". *Graduation Thesis in Computer Engineering*, University of Florence, 18 September 2007.

[6] M. Sainz and R. Pajarola, "Point-based rendering".*Computers and Graphics*, vol. 28, pp. 869-879, 2004.

[7] P.E. Debevec, C.J. Taylor and J. Malik, "Modelling and rendering architecture from photographs: a hybrid geometry and image-based approach". *ACM Proceedings of SIGGRAPH 96*, New Orleans, USA, 4-9 August 1996. 518 pages: 11-20

[8] P. Debevec and J. Malik, "Recovering high dynamic range radiance maps from photographs". *ACM Proceedings of SIGGRAPH 97*, 3-8 August 1997, Los Angeles, CA, USA. 494 pages: 369-378

[9] K. Pulli, K. Abi-Rached, H. Duchamp, T. Shapiro, and W. Stuetzle, "Acquisition and visualisation of coloured 3-D objects". *Proceedings of the 4th IEEE International Conference on Patter Recognition*, 16-20 August, 1998, Brisbane, Australia, Vol. 1, 947 pages: 11-15

[10] F. Remondino and J. Niederoest "Generation of high-resolution mosaic for photo-realistic texture-mapping of cultural heritage 3D models". *Proceedings of the 5th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST04)*, 7-10 December 2004, Brussels, Belgium. 279 pages: 85-92

[11] E. Beauchesne and S. Roy "Automatic relighting of overlapping textures of a 3D model". *Proceedings of IEEE Computer Vision and Pattern Recognition*, 18-20 June 2003. Vol. 2, 742 pages: 166-173

[12] F.M. Weinhaus and R.N. Devich, "Photogrammetric texture mapping onto planar polygons". *Graphical Models and Image Processing 1999*, 61(1): 61-83

[13] D. Ortin and F. Remondino "Generation of occlusion-free images for realistic texture mapping". *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 2005*, 36(5/W17)

[14] J. Boehm "Multi-image fusion for occlusion-free facade texturing". *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 2004*, 35(5): 867-872

[15] A. Pelagotti, A. Del Mastio and A. Razionale "Active and passive sensors for artworks analysis and investigation", *Videometrics IX Proc. SPIE-IS&T, Electronic Imaging 2007*, Vol. 6491

[16] Remondino, F., El-Hakim, S., "Image-based 3D modelling: a review", *Photogrammetric Record*, 21(115), pp. 269-291

[17] Blais, F., "A review of 20 years of Range Sensors Development". *Journal of Electronic Imaging*, 2004, 13(1): 231-240