Recovering Registered Geometry and High Dynamic Range Texture with Coded Structured Light

Asla M. Sá
asla@impa.br

Paulo Cezar Carvalho
pcezar@impa.br

Luiz Velho
lvelho@impa.br

Instituto de Matemática Pura e Aplicada - IMPA
Estrada Dona Castorina 110
22460-320, Rio de Janeiro, RJ , Brasil

ABSTRACT

In the last two decades the problem of accurately capturing the geometry of an object was extensively studied, while the acquisition of high-quality textures only in recent years has become subject of research. In most cases, geometry and texture are acquired separately and a registration step has to be carried out to correlate them. In this work we describe the usage of a color coded structured light. The traditional use of color in coding was revised in [Sa02b], and we had shown that, by projecting complementary slides, the reflectivity restrictions on objects can be eliminated. In this paper, by varying exposure between pairs of complementary slides, we are able to recover high dynamic range images and geometry at the same time, already registered to each other.

Keywords

3D-Photography, Coded structured light, High-Dynamic Range Images.

1. INTRODUCTION

Objects can be described by geometric and photometric properties such as normal, curvature, color, texture and material reflectance. Shape acquisition is one of the fundamental tasks in scanning objects. The other equally important task is to recover its photometric attributes.

Among all techniques used to acquire range data, we concentrate on the coded structured light approach, which allows using off-the-shelf hardware, reducing significantly the cost of the scanner. The same camera used to acquire geometry can be used to acquire photometric properties.

In order to recover depth information with the help of structured light the triangulation principles is used. A laser plane can be projected into a scene and, assuming that the camera can see the projected laser, and that both are calibrated, depth information can be computed by triangulation once the laser plane is detected in camera image.

In order to get dense range information, the laser plane has to be moved through the scene. In an attempt to alleviate the problem of capturing only one depth line per image, a slide containing multiple stripes is projected onto the scene. To distinguish between different stripes they must be coded properly, in such a way that their location in the projector image plane can be identified. This type of encoding scheme is called *coded structured light* (CSL). A survey on CSL methods can be found in [Bat98] and in [Sa02a]. Much work has been done in this area recently and the literature is extensive [Sco01, Ber02, Len01].

The hardware used to project slides and capture images has a direct influence on measurement accuracy. In a more subtle way, scene illumination conditions and the object's surface features also play an important role. Detection of shadow regions – viewed by the camera, but not illuminated by the projector – is also important. These areas are characterized by having very small brightness compared to illuminated areas.

In section 2 we describe our acquisition pipeline. In section 3 some results are shown. Conclusions and future work are outlined in section 4.

2. ACQUISITION

Dada acquisition will be based upon two concepts: 1) we use temporal colored codes, that is, more than one colored slide has to be projected in order to recover coded projector positions; 2) for each slide, its negative is also projected (by negative we mean the slide obtained by taking the complement of each pixel with respect to the white color). Since we have to project more than one pair of complementary slides, we change exposure for each pair, allowing us to recover high dynamic range images.

2.1 Geometry

The methodology of successively projecting positive and negative slides is useful to obtain subpixel accuracy on boundary position. The position of the stripe edge **P** is computed as the intersection between line **AB** and line **EF** of the positive and negative patterns, respectively as shown in Figure 2. In [Trobina95] a comparison of the techniques for detecting stripe position can be found.

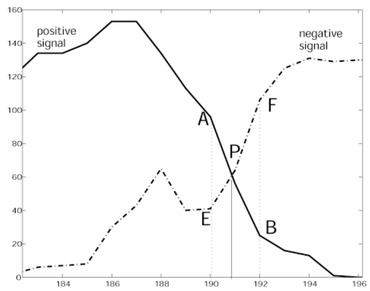


Figure 1 - Boundary detection procedure

Our boundary detection technique is based on pairs of complementary colored stripes. Two successive slides are projected with stripes of complementary colors. Each color channel is processed as in the one-channel inverse pattern edge detection method.

Considering that we are able to decode a pixel position code, the problem of establishing correspondence between camera pixels and projector pixels is reduced to an image processing task, responsible for identifying the transitions and the colors of projected stripes in the images captured by the camera. As we have adopted the vertical stripe boundary coding approach, scan lines can be treated independently.

2.2 Texture

The traditional use of color in coding restricts the object surface reflectivity, as we would not want to modify the projected colors in acquired images in order to recover coded pixel position. By projecting complementary slides, however, the reflectivity restrictions are eliminated [Sa02b], and in addition texture can be recovered.

The projector light beam is scattered from the object surface into a camera pixel. Let **u** be the ambient light component, **r** the local intensity transfer factor, mainly determined by local surface properties, and **p** the projector intensity for each channel [Malz99]. The resultant intensity measured per each channel is given by:

$$I_R = u_R + r_R p_R$$
$$I_G = u_G + r_G p_G$$
$$I_B = u_B + r_B p_B$$

We can estimate parameters **u** and **r** if we fix projector, sensor and object with respect to each other, and produce sequential projected patterns varying **p**. As mentioned previously, two complementary slides are projected, that is, if $p_i = 0$ on first slide then $p_i = 1$ on second. Thus:

$$I_i = \begin{cases} u_i, & if \;\; p_i = 0 \\ u_i + r_i, & if \;\; p_i = 1 \end{cases}$$

Taking the maximum value per pixel for each channel in the complementary slides is equivalent to recovering the value of each pixel as if it were illuminated with white light coming from the projector; thus, it corresponds to the situation where **p** = (1,1,1). Equivalently, taking the minimum value per pixel for each channel, corresponds to recovering the ambient light, that is, **p** = (0,0,0). In addition, the color of the projected light can be recovered if we treat channels separately.

One problem in the use of color coding is the cross-talk between the RGB sensors. In that respect, color fidelity can be improved by a color correction pre-processing step that takes into account the response of the projector-camera system.

3.3 High Dynamic Range Images

To recover high dynamic range textures we use HDRShop [Debevec]. Since we use more than one pair of complementary slides, we expose each pair differently. The images resulting from processing the pairs of complementary slides, as explained in the previous section (i.e., by assigning to each pixel the value as if it were illuminated with white light) are used as input images to HDRShop. The characteristic curves of our camera were precomputed and are also used as input. Notice that if HDR images are not used, information at overexposed or underexposed areas will be lost due to a limitation on device, not on methodology.

The relative positioning of camera and projector produces shadow regions, that is, regions viewed by the camera and not illuminated by projector. In these regions, information is lost and geometry cannot be recovered from this point of view.

We identify shadow areas by analyzing the magnitude of intensities in the HDR images. A point is in shadow if the absolute value in the three channels of the HDR. Using HDR images we are increasing the chance of not classifying surfaces of low reflectivity as shadow areas, which is common with usual images (in black painted areas, for example).

3. RESULTS

The code used in our experiments is (3,2)-BCSL, proposed in [Sa02b]. Results are shown in figures 3 and 4. In figure 3(a) the first pair of complementary projected slides is shown, from these two images we are able to recover the texture of the object as if it were illuminated with white light (fig 3(b)), as explained in section 2.2.

(a) First pair of (3,2)-BCSL complementary slides.

(b)Object illuminated with real white light (left) compared to the recovered white light from processing a pair of complementary slides (right).

Figure 3 – (3,2)-BCSL results

In figure 4 we have fixed the camera exposure to acquire the first pair of complementary slides, figures 4(a) and (c), and then we change camera exposure for the acquisition of the second pair, figs 4(b) and (d). The white light can be recovered by processing the two pairs and the HDR image is then reconstructed using images 4(e) and (f). Figures 4(g) and (h) are the images acquired when white light was projected into the scene.

We observe artifacts in the region of stripes transitions in figures 4(e) and (f) as well as in figure 3(b). This is due to the fact that camera sensors integrates information of a neighborhood of the scene point, this will always cause artifacts in regions where illumination change abruptly. A color calibration of camera and projector would be necessary to improve our results.

Geometry is acquired with high accuracy in the transition of stripes, where a noisy texture is recovered by camera sensors (see figure 3(b), 4(e) and (f)). On the other hand, in the middle of stripes, textures are recovered with high quality while geometric information is poor. Currently, we are working in improve the quality of texture information in transition areas.

4. CONCLUSIONS

The method described is able to recover geometry and high dynamic range texture of an object from the same set of images captured by a camera. This gives us a range image with registered texture without any additional effort. Registration of photographic images with range images is not an easy task and we are avoiding its need.

Instead of use (b,s)-BCSL, a colored version of Gray code - where each channel of a colored slide corresponds to one slide of the monochromatic Gray pattern - could be used. This approach divides by three the number of slides required to achieve the same resolution required by the classic Gray code, but for robustness in decoding the complementary slides have to be projected.

This work is part of a long-term research project that deals with the complete pipeline of 3D-photography acquisition. A potential extension would be to adapt our method to acquire data in real-time, as done in [Holt01], but also recovering registered texture information.

5. REFERENCES

[Bat98] J. Batlle, E. Mouaddib and J. Salvi. Recent Progress in Coded Structured Light as a Technique to Solve the Correspondence Problem: A Survey. Pattern Recognition 31(7), pp.963-982, 1998.

[Ber02]F. Bernardini, H. E. Rushmeier: The 3D Model Acquisition Pipeline. Computer Graphics Forum 21(2): 149-172 (2002)

[Debevec] P. Debevec and J. Malik. Recovering High Dynamic Range Radiance Maps from Photographs. SIGGRAPH..

[Holt01] O. Hall-Holt and S. Rusinkiewicz. Stripe boundary codes for real-time structured-light range scanning of moving objects. ICCV, pp.13-19, 2001.

[Len01] H.P.A. Lensch, M. Goesele, and H.-P. Seidel. A Framework for the Acquisition, Processing, Transmission, and Interactive Display of High Quality 3D Models. In *Tutorial Notes for DAGM 2001*, September 2001.

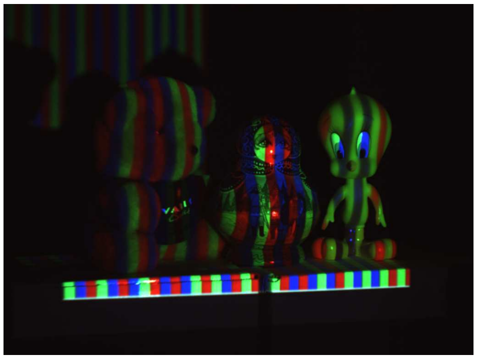
[Malz99] R. W. Malz. 3D sensors for high-performance surface measurement in reverse engineering. Handbook of computer vision and applications vol. 1, cap 20.

[Sa02a] A. M. Sá, E. S. M. Filho, P. C. P. Carvalho and L. Velho. Coded Structured Light for 3D-Photography: an Overview. RITA vol 9(2), pp 203-219.

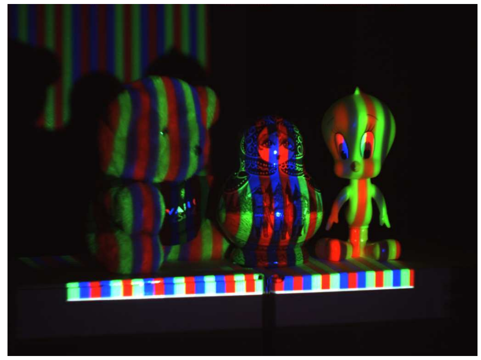
[Sa02b] A. M. Sá, P. C. P. Carvalho and L. Velho. (b,s)-BCSL: Structured light color boundary coding for 3D photography. VMV 2002 proceedings.

[Sco01] C. Rocchini, P. Cignoni, C. Montani, P. Pigni and R. Scopigno. A low cost 3D scanner based on structured light. EUROGRAPHICS 2001 20(3), pp.299-308, 2001.

[Tro95] M. Trobina. Error model of a coded-light range sensor. Technical Report BIWI-TR-164, Communication Technology Laboratory, Image Science Group, ETH Zirich, 1995.



(a) slide 1 - positive



(b) slide 2 - positive

(c) slide 1 – negative

(d) slide 2 – negative

(e) recovered “white” light from first pair

(f) recovered “white” light from second pair

(g) real white light

(h) real white light

Figure 4 – Test 3: (b,s)-BCSL code captured with different exposure