DIGITALISATION ET MODELISATION D'OBJETS 3D COLORES

COLOR DIGITIZING AND MODELING OF FREE-FORM 3D OBJECTS

Heinz Hügli & Timothée Jost

Institut de microtechnique
Université de Neuchâtel
Rue Breguet 2
CH-2000 Neuchâtel
Tél: 032 718 34 55
Téléfax: 032 718 34 02
E-mail: heinz.hugli@imt.unine.ch

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H. Hügli & T. Jost
IMT, Université de Neuchâtel (Suisse)

Résumé

Cet exposé aborde l'acquisition et la modélisation de la couleur d'objets tridimensionnels mesurés au moyen d'un scanner. On rencontre ce problème typiquement lors de la génération de modèles colorés réalistes pour des objets réels. Il présente deux aspects principaux qui sont considérés en séquence. Le premier est la nécessité de la mise en correspondance de la couleur et de la géométrie. Celle-ci est avantageusement satisfaite en choisissant un scanner qui fournit par principe une géométrie et la couleur correspondante. Le deuxième aspect du problème est la fidélité de la couleur. Cette partie est bien plus cruciale car les composantes délivrées par le scanner représentent les intensités de la lumière réfléchie par l'objet et non la couleur intrinsèque souhaitée pour le modèle. On présente et analyse différentes méthodes disponibles pour convertir ces composantes dans les couleurs du modèle.

Abstract

This presentation addresses the color capturing of a free-form 3D object measured with a range scanner. This problem appears typically in a modeling procedure that aims to build a realistic colored 3D model. Its two main aspects are considered in sequence. The first aspect is the requirement of a good registration of color and geometry. This part of the problem is best solved at the source by choosing a range scanner, which, from its principle of operation, provides a priori registered color measurements. The second aspect is color fidelity. This part of the problem is more crucial as the color components delivered by scanners express the reflected color intensity of the object and not its intrinsic color as required for the object model. Several methods available to convert measured color components into model colors are presented and discussed.

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1. Introduction

The modeling of real 3D objects consists basically in the measurement of the object geometry and the construction of an adequate representation. This basic geometric modeling does however not cover the requirements of a whole range of applications, for which the appearance of an object is also required. Realistic appearance is obtained by assigning color to the model. Capturing of color becomes therefore an additional task of the digitizing and modeling process.

This paper focuses on the capturing of color information of physical 3D objects by range scanners and on the building of the respective color model.

The first aspect is the measurement of color. A color range scanner is thus required. A first part of the paper is devoted to a discussion of various kinds of range scanners and on the suitability of some principles for color measurements.

The second aspect is color fidelity. This part of the problem is more crucial as the color components delivered by scanners express the reflected color intensity of the object and not its intrinsic color as required for the object model [1] [2]. In general, problems and solutions will vary depending on the task and on the kind of color digitizing device. This paper analyses more specifically some problems encountered with color modeling from color images obtained by a structured light range sensor. Several methods available to convert measured row color components into model colors are presented. Some experiments, conducted in order to test their effectiveness are presented and typical results are shown and discussed.

2. Color range scanners

Various types of 3D scanners or range scanners can be found on the market today. Beside the traditional tactile sensing devices, most of these devices are based on vision, which offers the advantage of having no physical contact with the measured object. These tools measure the spatial position of points on a surface and usually provide the result as a range image, the value of each pixel being the point-to-scanner distance. One can mainly distinguish four measurement techniques: passive triangulation, active triangulation, laser radar and focus:

- Passive triangulation, or stereo vision, uses at least two different views of the scene. Low level features are then directly matched. Range information can be obtained, knowing the relative position and orientation of each camera.
- In active triangulation, a light spot, line or grid is projected on the object and observed from a different angle, by a CCD camera. Range data can be computed by triangulation.
- For laser radar, a laser beam is directed on the object and data is calculated thanks to time of flight or phase shift measurements.
- Finally, the focus technique determines the range value of a point, considering the lens configuration that gives the best focus for this point.

For color measurements, in addition to measuring the range, a scanner must be in a position to measure color. Not so many color range scanners are currently available. The transition from pure geometric scanning to measuring color requires extending the scanner capabilities.

Basically, it is expected that a color 3D scanner measures the geometry and color or the real object. More specifically, a color range scanner will provide the object measurements as two maps, a range and a corresponding color map. The word *corresponding* means that range and color maps need to be aligned, i.e. same positions of the maps measure the same position of the measured real object. An example of aligned range and color images is given here.

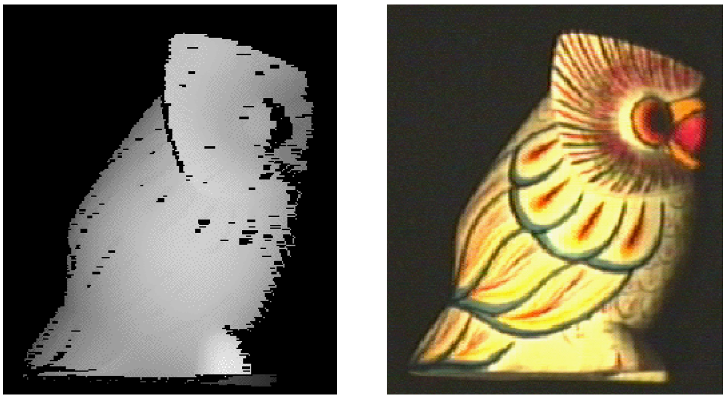


Figure 1. (a) Range image (b) Color image

Not all range scanner techniques are equally well suited for measuring color. Considering above mentioned range measurement techniques, only some of them can be easily extended to color. First of all, the tactile, non-vision technique lacks the basic sensing devices for light and consequently also for color: it is therefore not suited. Then, time-of-flight sensors make use of laser light for light delay measurements. Using basically monochromatic light, this system cannot measure color and an extension to color would require fundamental system redesign: it is not suited. In contrast, the other three techniques, passive triangulation, active triangulation and focus are more suited for color measurements. In fact, they have all in common the sensing of the scene by a camera. The extension to color of such a system is therefore straightforward, as it consists simply in the replacement of the monochrome camera by a color camera and by adding the related processing.

Let us mention few examples of color range scanners. NRCC developed a color range scanner known as the RGB laser scanner in the early 90 [3]. It uses active triangulation between a laser spot and a linear CCD. The extension to color consists mainly in the extension of the system with three laser sources and the separate measurement of the three components. The VIVID scanner is an active triangulation scanner that uses structured light [4]. The extension to color is by the simple use of a color camera. TRICLOPS is a stereo range scanner and can therefore also benefit from color delivered by a color camera [5].

As color range scanners are expected to deliver registered range and color maps, it is important to select a range scanner that provides good registration. Scanning techniques that offer this registration from their basic principle of operation are thus best suited and should be preferred.

Not all kind of scanners can be discussed in the paper. For the rest of the paper, we will consider specifically the case of data obtained by a structured light range scanner as illustrated here.

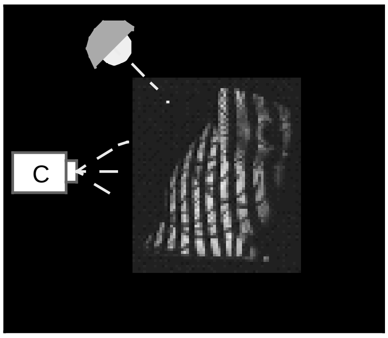


Figure 2. Structured light color range scanner

3. Color object modeling from range images

Object modeling starts with the acquisition of several views by successively changing the object pose under the scanner. It is required that the set of acquired range views collectively covers the whole object surface.

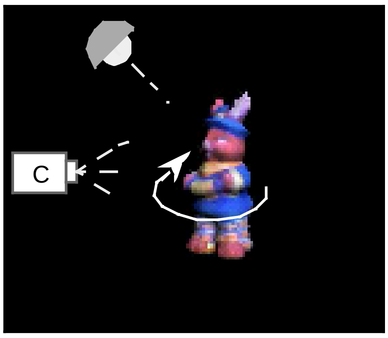


Figure 3. Acquisition of a set of views

The task of object modeling from range images then mainly consists in merging this set of views in order to end up with a unique surface for the object [6]. It can be divided in two main parts described hereafter: positioning and integration. The related color processing is then exposed.

3.1. Positioning

Positioning is the attempt to find the correct relative alignment of two or more views. This is straightforward if, during the acquisition process, the object is kept into a calibrated configuration, like on a turntable. Also, in some cases, positioning is not performed during the acquisition and must be solved at a later stage by registration [6].

3.2. Integration

After registration, the views need to be integrated together, in order to be left with a unique surface for the virtual object. A wide variety of methods are available, from keeping most of the original structure of the views to building a whole new surface from the cloud of points formed by the registered views. Whatever method is used, color problems, like discontinuities, may appear if one tries to mix colors that are not the same on different views.

3.3. Color representation

Two forms of color representations are possible and lead to either the colored or the textured object representation. With the colored representation, a color is attributed to each vertex of a grid. With the texture representation, a small image is attributed to each face of a grid.

Special care is expected in the treatment of color during the integration phase [9]. One principle of the integration step is to remove the overlapping part of one of the views, namely P, and to fill the resulting gap between P and the other surface X. A procedure named texture extension chooses among P and X the texture with the best properties. Another procedure named *texture-averaging* smoothes the color transitions by filtering.

4. Intrinsic color recovery methods

Sensed colors or intensities depend on the object and on its illumination as well. This means that the sensed color of the same point of an object will generally not be the same under different illumination conditions. These acquisition effects produce discontinuities in the reconstructed model. Recovery of the intrinsic object color is both a remedy to this problem and can also be a basic goal of object modeling.

This section describes the problem of intrinsic color recovery and proposes different solutions that are developed for a structured light range scanner. The first method retrieves the intrinsic object color in a configuration where the projector is the only source of illumination. The second and third methods use additional light sources.

4.1. BRDF

Light reflected on the surface of an object depends on the incident light and on light interactions near the surface of the object that result from several physical phenomenon. The most general description of the geometrical relations of incident and reflected light is given by the bi-directional reflection distribution function but this BRDF is a function of four variables it is too complex to be of practical interest in this context. Simpler models of light reflection are therefore considered.

4.1. Reflectance model

A reflectance model is a simple approximation of the light reflection phenomenon: when light strikes the surface of an object, part of it is reflected, part is absorbed and part is diffused. The reflected light *bounces* off like in a mirror and is referred to as specularity. The diffused light is colored by the object surface properties.

According to the simple Lambert model [8], diffusion emits light in equal quantities in every direction. For a single light source, along direction **S**, the radiance is thus given by

$$L(\mathbf{V}) = L = k_d L_s (\mathbf{S} \cdot \mathbf{N}) = k_d L_s \cos\theta \qquad (1)$$

where L_s is the radiance of an ideally white surface oriented towards the light source, k_d is a constant depending on the object material, **N** is the surface orientation (normal) and θ is the angle between **S** and **N** (fig. 4., every vector has a norm of 1).

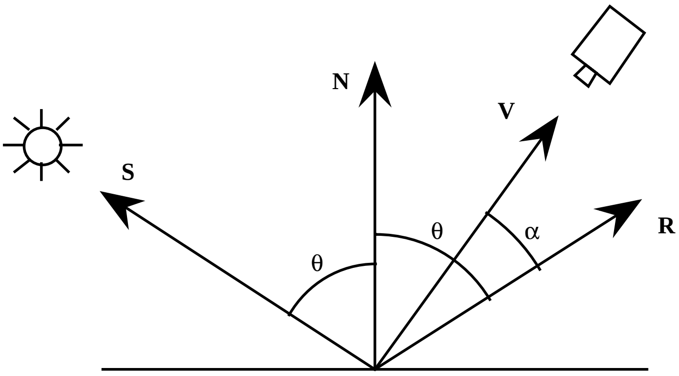


Figure 4. Radiance along V of a surface illuminated from S

We can easily recover k_d from (1)

$$k_d = \frac{L}{L_s \cos\theta}$$

k_d is the reflection coefficient of the surface. In the perfect case, it's value ranges from 0 for black to 1 for white. It is the expected intrinsic object feature.

In addition to this diffuse component, the Phong model [7][8] takes also ambient light and specularity into account. It uses an exponentiated cosine to model the specular highlights:

$$L(\mathbf{V}) = k_a L_a + k_d L_s (\mathbf{S}\cdot\mathbf{N}) + k_s L_s (\mathbf{R}\cdot\mathbf{V})^{k_e} = k_a L_a + k_d L_s \cos\theta + k_s L_s (\cos\alpha)^{k_e} \qquad (2)$$

where k_s is a scalar constant, k_e is called roughness or shininess exponent and **R** is the specular reflection direction (fig. 4.), given by the simple relation

$$\mathbf{R} = \mathbf{S} + \mathbf{2}(\mathbf{S}\cdot\mathbf{N})\mathbf{N}$$

k_a L_a is called ambient light. It takes indirect light effects into account. Indirect lightning is the result of reflection or transmission of light on other objects, walls etc... that indirectly illuminates the considered object. Of course, this is a very simple approximation because it considers indirect lighting as constant everywhere, but we will see later that it has some practical importance.

4.2. First method: Single light compensation

This method considers the object illuminated by a single source of light, which is the projector of the structured light range finder. The goal is to invert the reflectance model in order to compensate for varying light illumination. Illumination and camera position are known from the calibration process and surface orientations can be computed from the range data.

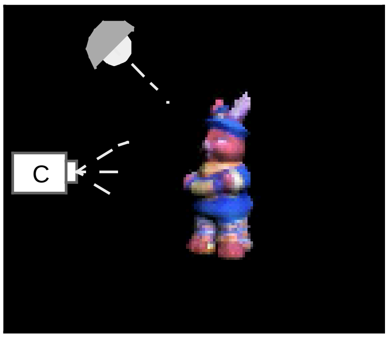


Figure 5. A single illuminator

Considering the Phong model (2), the problem is that, generally, it can't be inverted near the specular direction. Practically, the specular component is so intense near that direction that the image is saturated, leaving no information about the intrinsic color of the object. Thus, for this model, we will keep only the diffuse and ambient component. This gives the relation:

$$k_d = \frac{L/L_s - k_a L_a / L_s}{\cos\theta} \qquad (3)$$

To measure the incoming light, we use a CCD camera and a frame grabber. The video signal is converted into a digital red, green and blue (r,g,b) signal to create the color image. In our case, the radiance is proportional to the color vector and, consequently, we will use (3) on each component of the $\mathbf{C} = (r, g, b)$ vector:

$$\boxed{\mathbf{C_d} = \frac{\mathbf{C} - \mathbf{C_a}}{\cos\theta}} \qquad (4)$$

where $\mathbf{C}$ is a pixel of the color image and $\mathbf{C_a}$ is the ambient component.

Note that the image acquisition device often delivers a signal that is affected by some offset value. The ambient term compensates also for this unwanted offset.

4.3. Second method: Constant illumination

Instead of trying to use one known light source and convert the reflected color intensity back into intrinsic color, the second approach aims at using a nearly constant, diffuse and omnidirectional illumination over the visible parts of the object. The goal is to create an infinite number of very small light sources that illuminate each visible face of the object from every direction.

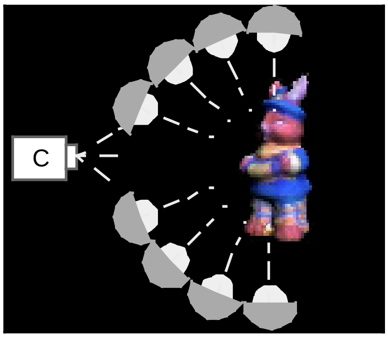


Figure 6. Constant illumination

4.4. Third method: Multiple light compensation

A disadvantage of the first method is that it fails in presence of specular reflection. In order to overcome this problem, the idea is to successively use several light sources at various positions and orientations and to acquire each time the respective color image: the data now consist of one range image and several color images. The resulting image is computed by weighted averaging of each compensated input images.

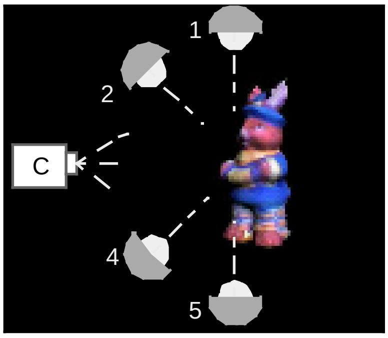


Figure 7. Multiple illuminations

The present method uses the Phong model. The goal here is to consider one color image per light source position. Each of these images is modeled by

$$L_i(\mathbf{V}) = k_a L_a + k_d L_i (\mathbf{S}_i \cdot \mathbf{N}) + k_s L_i (\mathbf{R}_i \cdot \mathbf{V})^{k_e} = k_a L_a + k_d L_i \cos\theta_i + k_s L_i (\cos\alpha_i)^{k_e}$$

Because *same light sources* are used at approximately the *same distance*, the radiance of each source is constant: $L_i = L_s, \forall i$. To simplify the relation, from now on, we will consider offset compensated and normalized images: $L_i^{'}(\mathbf{V})$. Considering diffusion, for each image, and an adequately weighted average k_d for n sources [9] leads to the compensation transform:

$$\boxed{\overline{\mathbf{C_d}} = \frac{\sum_{i=0}^{n-1} \left(1-(\cos\alpha_i)^{k_e}\right)^{k_o} (\mathbf{C_i} - \mathbf{C_a})}{\sum_{i=0}^{n-1} \cos\theta_i \left(1-(\cos\alpha_i)^{k_e}\right)^{k_o}}} \qquad (6)$$

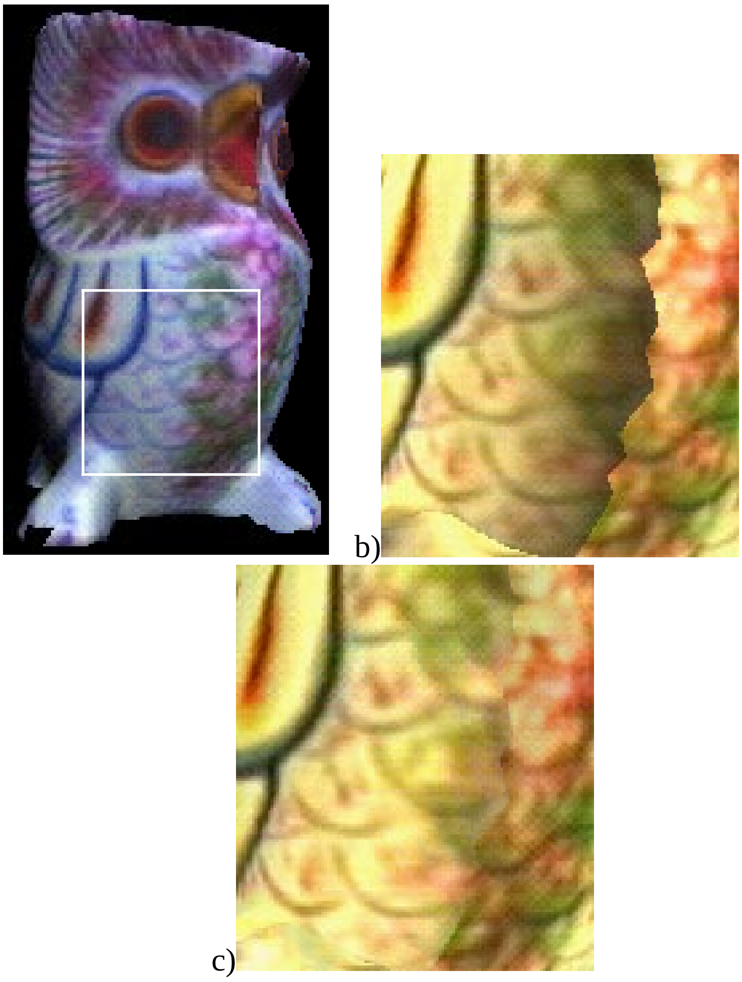
where $\mathbf{C_i}$ is a pixel of the color image i and $\mathbf{C_a}$ is the ambient component.

5. Experiments

The following section presents experiments conducted in order to validate and compare the different methods. The color range scanner consists of a JVC/VC 4913 color CCD camera an ABW LCD-320 projector. The modeling software is described in []. Reproduction light spots and diffusers are used for the extra illumination.

5.1. Comparison of the methods regarding diffusion

This is a practical evaluation of the three methods in the context of object modeling. The task consists in the modeling of a mainly diffuse, painted wooden owl by merging of 8 single views. Figure 8 illustrates the reconstructed owl model and depicts two variant of a detail view of it. Detail b) illustrates the model obtained from merging row color views and detail c) shows the improved view obtained with the intrinsic color views. Note that the three methods produce similar results in this task.



a) b)

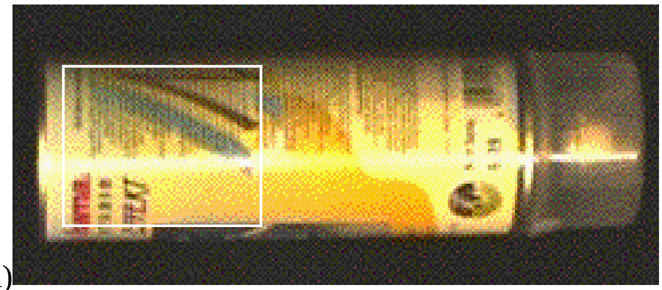
c)

Figure 8: a) Owl model with detail view, b) row color, and c) intrinsic color

5.2. Comparison of the methods regarding specularity

This is a comparison of the three methods for a highly specular object, a metallic spray can. Each method was applied to the same view of the spray.

Figure 9 presents the results in the form of the raw color (top) and the intrinsic colors (bottom) according to the three different methods. As expected, the first two methods keep the specular reflection in the image. The second method reduces them but tends to create several reflections. Only the multiple light compensation method shows to be successful here, the specular reflections being nearly invisible.



a)

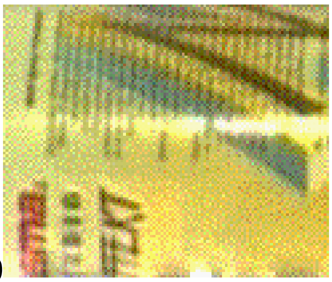
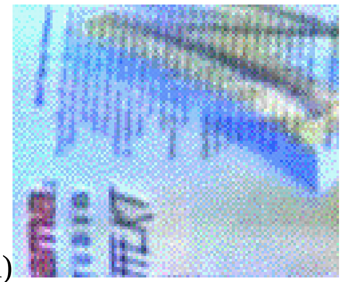
b)  c)  d) 

Figure 9. a) Spray can model with detail views, b) method 1, c) method 2, and d) method 3

5.5. Discussion

The first method uses the sole range scanner; it has the advantage of not requiring additional illumination. Highly reflective objects can pose a problem, because specularity isn't considered in the final model. Furthermore, colors near the boundary of the views (large incidence angles) tend to have a higher uncertainty.

The second and third methods require additional hardware, namely external sources of light. For method two, obtaining a real constant illumination needs some effort. For object of low specularity, this method tends to provide better results than the first method but the results are bad with highly specular objects.

The third method is the only method to be effective in presence of specular reflections.

6. Conclusion

This paper shows that the generation of intrinsic color virtual models from free-form real objects requires special attention. In essence, it considers object acquisition by a structured light color range scanner and discusses three simple methods that can be used in order to recover the intrinsic colors of a captured object. The first one uses the projector as unique light source and converts the reflected color intensity into the intrinsic color by computation, using a reflectance model and known acquisition parameters. The second approach is a hardware solution: it aims at using a nearly constant, diffuse and omnidirectional illumination over the visible parts of the object. A third method combines the first computational approach with the use of several known illumination sources.

The results confirm that these methods can be successfully applied to a number of objects. The experiments show that the first simple method works satisfactorily in presence of diffusing objects. In presence of specular objects, the more sophisticated third method is recommended.

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