Projector-Camera Structured Light Using Photometric Ratios

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Abstract

Conventional light striping systems capture 3D data by stereo reconstruction and employ encoding systems to solve the correspondence problem. A confounding factor in this overall framework is the interaction of light with surfaces. Light is absorbed by materials and current methods tend to perform poorly for dark objects. We present a new approach to projector-based structured light that uses reflectance ratios for invariance to surface albedo. We demonstrate promising results for traditionally difficult areas such as black portions of objects and dark hair. Consequently, this approach may be particularly useful in the area of people sensing.

1. Introduction

Also known as structured light and active illumination, light striping methods are used to acquire 3D information by projecting light stripes and observing the scene. When the camera and projector are calibrated so that their relative position is known, triangulation can be used for three dimensional shape reconstruction. The difficult part in the process is the correspondence problem, matching the projected pattern or stripe with a particular observed scene point. Conventional structured light systems solve the correspondence problem by having the projector encode the scene with patterns. Gray coding is one such traditional approach. Several projected patterns are thresholded into a binary image creating a sequential pattern of ones and zeros. Examples of gray code in structured light systems include [4] and [1]. Another approach uses a projection of stripes with different colors and dynamic programming to optimize the matches [6]. Methods that emphasize the projected stripe edges aid the correspondence. For example, [7] uses a moving stripe pattern and then looks for spatio-temporal edges to isolate projected stripes. Another method specifically encodes the boundaries between projected stripes [2] obtaining real time performance suitable for moving objects. Still another approach uses an adaptive pattern [3] and a weighted sum of multiple cues. But while many of these methods obtain impressive results for light-colored objects, the results are not shown for multicolored objects with dark regions. These types of objects remain problematic for current methods which rely on spatial edges or even spatio-temporal edges, both of which are not difficult to detect in dark regions.

2. Method

Motivated by the problem of using projector-camera systems to ascertain the shape of human subjects, we developed an approach that could work on both dark and light regions. We create a temporal gradient in the projected stripe pattern. Consecutive stripes are projected onto a scene and then reprojected with a different intensity. The temporal gradient in intensity can be chosen arbitrarily and we choose a gradient that enhances projected edges. In particular alternate stripes are given a positive gradient (increasing intensity) and negative gradient (decreasing intensity). The ratio of the two consecutive image gives an estimate of this temporal gradient. Moreover, for Lambertian surfaces these ratios are invariant to albedo variations[5]. In our experiments, the invariance works well even for non-Lambertian objects. The resulting stripes are cleanly segmented even in dark regions (see Figure 2). This ratio method can be used in a variety of ways and here we choose to use them in a simple binary code to determine the projector stripe id number for every pixel in the image. This approach is far superior than thresholding the raw intensity values (see Figure 2).

Let I(x,y) be the pattern projected by the projector. Because vertical stripes were the chosen projected pattern we can remove the dependence on y so that the projected pattern is expressed as $I(x)$. We introduce a temporal gradient by increasing or decreasing the intensity of the stripe pattern by $c(t)$. Therefore, the actual projected intensity I_p can be expressed as

$$I_p(x,t) = c(t)I(x). \tag{1}$$

Letting c(t) be a multiple of t, Equation 1 becomes

$$I_p = (a(x)t)\, I(x), \tag{2}$$

where a is a scale factor that alternates from stripe to stripe. Then,

$$\frac{\partial I_p}{\partial t} = a(x)I(x). \tag{3}$$

In practice, the ratio r from two consecutive time instances is computed. Then r is compared to unity to determine which areas are increasing and which are decreasing. The ratio image for a real image is shown in Figure 2. Notice the edges are readily apparent *independent* of the surface albedo. Therefore, this ratio pattern can be detected well in dark areas. To properly image the dark regions we use high dynamic range imaging by employing the auto bracketing option of the digital camera[1].

Figure 1. Original image with projected stripes (left). Ratio image (right). Clearly thresholding or edge detection in the original image will be problematic in the hair region. However, the ratio image shows strong unattenuated edges in this region.

3. Experimental Results

For this work, we reconstructed a checkerboard cube (chosen for its numerous dark regions) and a human head including hair. Figure 3 and Figure 2 show the objects and the reconstructions are shown in Figure 3 and Figure 3. It can be seen that the reconstruction in the dark areas is more accurate with ratio method than with the Gray code method. Notice the protrusions from the dark areas in the reconstruction of the cube using Gray code. These protrusions are far less apparent in the reconstruction using the ratio method. In the face reconstruction, Gray code performs poorly in reconstructing the region with hair. With the ratio method, notice how the estimated shape captures the hairline near the sideburns and also the "bangs."

Figure 2. Black/White Cube

4. Conclusion

We present a new method of shape recovery using structured light projector-camera systems. The new method shows promising results in multicolored objects and traditionally difficult dark areas such as hair. Using a ratio of light intensities enables albedo invariance which is a key feature of the approach.

[1]Camera: Nikon D2H digital SLR. Projector: Mitsubishi projector model XD60U XGA 1800 Lumens

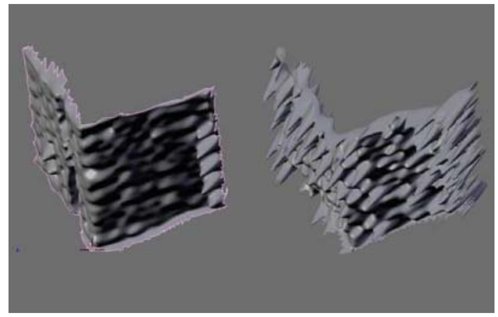

Figure 3. 3D Reconstruction using the ratio method (left) and using the Gray code (right). Notice that the darker regions have significant errors using the standard Gray code method.

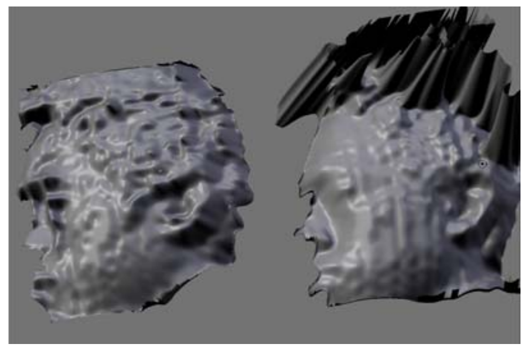

Figure 4. Reconstruction using the ratio method (left) and using the Gray code (right). Notice the details in the dark regions of the hair and the edges.

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