Automatic Highlight Removal in Visual Hull Rendering by Poisson Editing

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ABSTRACT

In image-based visual hull (IBVH) rendering, highlight spots in reference images often cause undesired artifacts in the rendering results. In this paper, we propose a method that can automatically recognize and remove highlight spots from reference images, by utilizing the features of IBVH. First, highlight sub-images are extracted by histogram analyzing; then, their counterparts in other images are calculated. The highlight pixels can be retrieved from their corresponding pixels by pixel blending, and finally be seamlessly integrated back into the target image by resolving a Poisson equation.

Categories and Subject Descriptors: I.3.3 [Computer Graphics]: Picture/Image Generation – Display algorithms; I.4.3 [Image Processing and Computer Vision]: Enhancement – Filtering.

Keywords: Image-based Rendering, Shape-from-Silhouette, Image Editing, Highlight.

1. INTRODUCTION

Visual hull (VH) rendering technique takes a group of images of a target object as input, and produces an approximate convex hull of the object, so that it could be rendered from arbitrary new viewpoint. As an image-based method, it often suffers from the highlight spots in the input images, which would cause undesired artifacts in rendering results.

A typical type of highlight removal technique requires a flash/no-flash image pair at a single position [Petschnigg 2004, Agrawal 2005]. Combining the ambient qualities of the no-flash image and the high-frequency detail of the flash image, a new image without highlights can be synthesized. Although these methods are effective for single-view, they are not practical in VH rendering, because they will largely increase the difficulty of acquiring source images and the computing complexity.

Another kind of methods works on a single image. [Tan 2003] utilizes potential useful information contained by highlight pixels to guide the process of image inpainting; [Pérez 2003] changes local illumination by applying a non-linear transformation to the gradient field in selected highlight area. However, they only work well in areas with simple or regular textured background, and cannot guarantee the consistency of corresponding areas in different source images, which is very important in VH rendering.

In fact, visual hull method itself provides much convenience for highlight removal. The input reference images usually have a lot of overlaps. Such redundancy will offer sufficient information to remove highlights.

In this paper, we adopt a similar framework as the Image-based Visual Hull (IBVH) method [Matusik 2000]. We automatically extract the sub-images containing highlight spots from a reference image. Their counterparts can be found in other reference images, so that they can be resampled from these counterparts and the highlight spots can be removed. To guarantee the boundary continuity, we also adopt a seamless integration method to optimize these new sub-images.

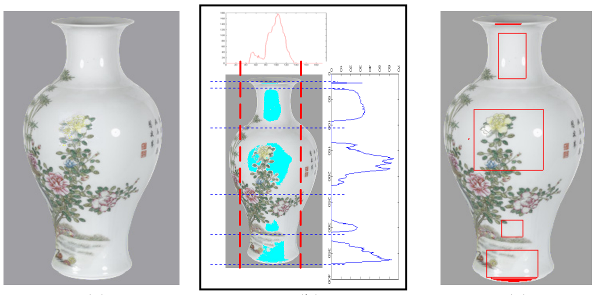
2. HIGHLIGHT SUB-IMAGE EXTRACTION

The highlight sub-images in a target reference image must be extracted first. The subsequent calculations will be restricted to these sub-images, to guarantee the computing efficiency and image fidelity.

First, the brightest pixels of the image are automatically recognized and considered as highlight pixels by analyzing the intensity histogram of the target image. Then, these discrete highlight pixels are grown into connected regions by a seed filling method to prevent the appearance of fragmentary sub-images. The extended highlight pixels are further classified into several groups, by analyzing their vertical and horizontal histograms, and a C-average classification method (as illustrated in Fig. 1(b)). Finally, highlight sub-images can be easily extracted by finding the bounding boxes of the classified pixel groups (Fig. 1(c)).

3. HIGHLIGHT SUB-IMAGE RESAMPLING

As illustrated in Fig. 2, for each highlight pixel p_0 in the target image I_0, there is a 3D ray r emitting from the camera center. Its projection on image I_k (denoted as l_e) intersects the silhouette of I_k at p_a^k and p_b^k. Their corresponding rays, r_a^k and r_b^k intersect with r



(a) (b) (c)

Figure 1. Automatic Highlight sub-image extraction. (a) Original; (b) Recognized highlight pixels and their histogram analysis; (c) Extracted highlight sub-images.

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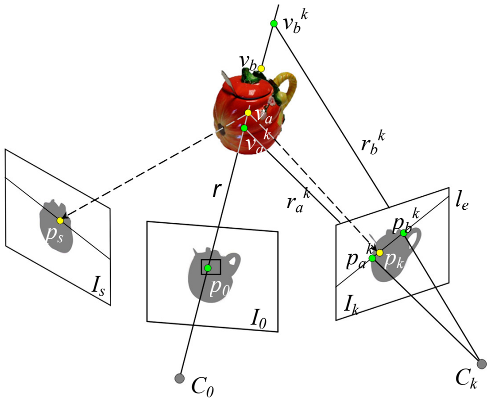


Figure 2. Finding the corresponding pixels of p_0 in other reference images.

and result in 3D segment (v_a^k, v_b^k). Repeating this calculation on all of the reference images, we get a group of such 3D segments. Their final intersection (v_a, v_b) is considered as the intersection of r and the visual hull, and the nearer endpoint v_a is the corresponding 3D point of p_0. Thus, v_a can be projected onto other images to get the corresponding pixels of p_0 (e.g. p_s and p_k).

Usually, due to the relative movement of the object and the light, most of the corresponding region of current sub-image is out of highlight area. Therefore, the color of a highlight pixel p_0 could be recalculated by blending the appearance colors of p_0 and its corresponding pixels $\{p_k \mid k=1\ldots n\}$ as follows:

$$C = \sum_{k=0}^{n} w_k C_k \,, \tag{1}$$

where $C_k=(R_k, G_k, B_k)^T$ is the color vector of p_k, and the weight w_k is calculated according to the intensity level of p_k: the pixels whose color deviate far from the others are given smaller weight, while those closer to the average color are given larger weight [Feng 2007]. Therefore, highlight spots can be removed, and the texture could be well preserved. The simple calculation makes this step very efficient.

4. SEAMLESS INTEGRATION OF RESAMPLED SUB-IMAGES

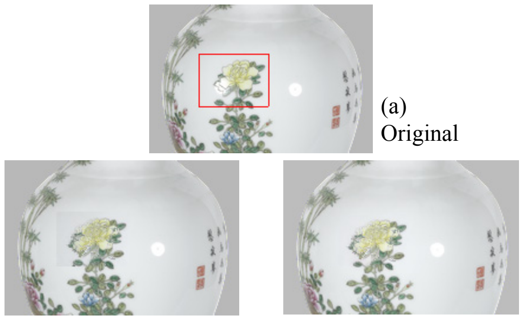
In some sensitive cases, the boundaries of the resampled sub-images are not continuous in color, and need further improvement (Fig. 3(b)). Here we adopt a seamless cloning method to integrate the resampled sub-images back into the target reference image.

The original method of seamless cloning [Pérez 2003] is applied in inserting a source image patch g into a destination image f^*. Finding the resulting patch f is equal to solving a Poisson equation:

$$\Delta f = div(\nabla g) = \Delta g \text{ over } \Omega, \text{ with } f\,|_{\partial\Omega} = f^*\,|_{\partial\Omega}\,, \tag{2}$$

where $\Delta.=\partial^2./\partial x^2+\partial^2/\partial y^2$, $div\mathbf{v}(u,v)=\partial u/\partial x+\partial v/\partial y$, $\nabla.=(\partial./\partial x, \partial./\partial y)$, and Ω is the patch domain.

In our case, we consider each resampled sub-image as a source image patch g and the target reference image as f^*. Therefore, solving the equation (2), we could get an optimized sub-image, which has smooth and continuous boundary, and can be seamlessly integrated back into the target image. Here we use successive over relaxation method to solve equation (2). Properly



(a) Original

(b) After resampling (c) After seamless integration

Figure 3. Highlight sub-image resampling and seamless integration.

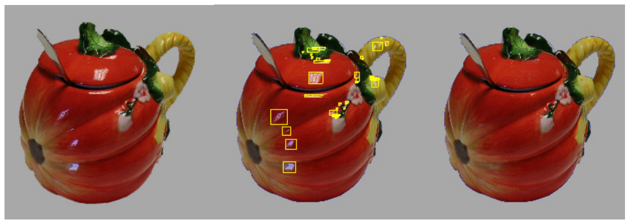


Figure 4. Experimental result of automatic highlight sub-image extraction and final highlight-free image.

controlling the number of iterations and the relaxation factor, the equation can be solved with both efficiency and accuracy.

5. RESULTS AND DISCUSSION

Here we applied our method to two sets of input images (each include about 20 images). The experimental results are shown in Fig. 3 and Fig. 4, from which we can see that the highlight spots are smoothly removed and the textures are well preserved, even in some complex areas. By seamless integration, the colors and textures are smooth over the sub-image boundaries. Using these fixed reference images, we can get more realistic rendering results, especially when the illumination changes.

In future work, we shall further improve the efficiency of the method so that it could work in real time. And the accuracy and stability are also very important topic to study on.

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