Specular Reflection Reduction Using a Multi-Flash Camera

Rogerio Schmidt Feris
University of California, Santa Barbara (UCSB)
Kar-Han Tan
University of Illinois, Urbana-Champaign (UIUC)

Ramesh Raskar
Mitsubishi Electric Research Labs (MERL)
Matthew Turk
University of California, Santa Barbara (UCSB)

Abstract

We describe a novel method to reduce the effect of specularities in digital images. Our approach is based on taking successive images of the scene with different light sources. We then exploit image reconstruction from gradient fields to obtain a specular-reduced image, useful for traditional photography and many computer vision methods.

1 Introduction

The presence of specularities in real scenes is very common and most often undesirable in traditional photography and image analysis methods, such as stereo reconstruction. Although a variety of methods have been proposed to remove specular highlights in a single image [Nayar et al. 1997], detecting them reliably in textured regions remains a challenging problem.

Our approach is similar in spirit to reducing the red eye effect in photography using a strobed flash. We rely on a simple modification of the capture setup: a multi-flash camera is used to take multiple pictures of the scene, each one with a differently positioned light source. Figure 1a shows our prototype, which can be packaged into a self-contained device no larger than existing digital cameras. This setup was successfully used for depth edge detection and stylized rendering [Raskar et al. 2004]. Next we describe how it can be used for specularity removal.

2 Exposition

Our method is based on the observation that specular spots shift according to the shifting of light sources that created them. We need to consider three cases of how specular spots in different light positions appear in each image: (i) shiny spots remain distinct on a high specular surface; (ii) some spots overlap and (iii) spots overlap completely (no shift). We show that for cases (i) and (ii), which often occur in practice, our method successfully removes specular highlights.

We note that although specularities overlap in the input images, the boundaries (intensity edges) around specularities in general do not overlap. The main idea is to exploit the gradient variation in the n images, taken under the n different lighting conditions, at a given pixel location (x,y). If (x,y) is in a specular region, in cases (i) and (ii), the gradient due to the specularity boundary will be high in only one or a minority of the n images. Taking the **median of** the n **gradients** at that pixel will remove this outlier(s). Our method is motivated by the intrinsic image approach [Weiss 2001], where the author removes shadows in outdoor scenes by noting that shadow boundaries are not static. Let I_k, $1 \leq k \leq n$ be an input image taken with light source k. We reconstruct the specular-free image by using median of gradients of input images as follows:

- Compute intensity gradient, $G_k(x,y) = \nabla I_k(x,y)$
- Find median of gradients, $G(x,y) = \text{median}_k(G_k(x,y))$
- Reconstruct image I' which minimizes $|\nabla I' - G|$

Emails: {rferis,mturk}@cs.ucsb.edu, raskar@merl.com, tankh@vision.ai.uiuc.edu

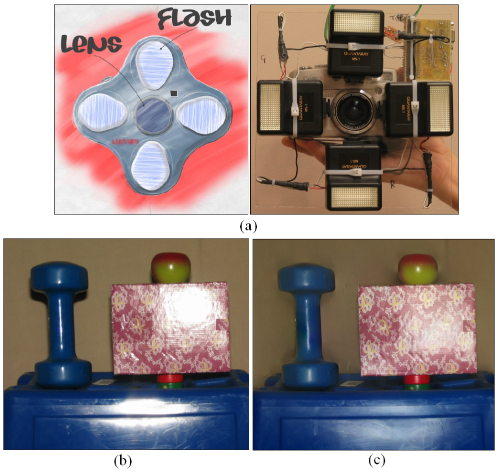

Figure 1: *(a) Our prototype with four flashes. (b) Image taken with one of the flashes. (c) Our result for specularity removal.*

Image reconstruction from gradients fields, an approximate invertibility problem, is still a very active research area. In R^2, a modified gradient vector field G may not be integrable. We use one of the direct methods recently proposed by [Fattal et al. 2002]. The least square estimate of the original intensity function, I', so that $G \approx \nabla I'$, can be obtained by solving the Poisson differential equation $\nabla^2 I' = div\, G$, involving a Laplace and a divergence operator. We use the full multigrid method to solve the Poisson equation.

Figure 1c shows the resultant intrinsic image intensity $I'(x,y)$ with significant removal of specularities, when compared with an image taken with one of the flashes in Figure 1b. Our method fails in rough surfaces or when specularities appear close to depth discontinuities in the scene.

Let $Imax(x,y) = max_k(I_k(x,y))$, $1 \leq k \leq n$. We note that specular pixels may be detected by just analyzing the ratio $I'/Imax$, which will be close to 1 only in non-specular regions. Detecting specularities (instead of removing them) would be useful in other applications, such as object shape information acquisition and interactive creation of technical illustrations, where the user may decide whether to keep or remove specularities.

References

FATTAL, R., LISCHINSKI, D., AND WERMAN, M. 2002. Gradient Domain High Dynamic Range Compression. In *Proceedings of SIGGRAPH 2002*, ACM SIGGRAPH, 249–256.

NAYAR, S., FANG, X., AND BOULT, T. 1997. Separation of reflectance components using color and polarization. *International Journal of Computer Vision 21*, 3, 163–186.

RASKAR, R., TAN, K., FERIS, R., YU, J., AND TURK, M. 2004. Stylized images using a multi-flash camera. In *Proceedings of SIGGRAPH 2004 (to appear)*, ACM SIGGRAPH.

WEISS, Y. 2001. Deriving intrinsic images from image sequences. In *Proceedings of ICCV*, vol. 2, 68–75.