Digital Photography with Flash and No-Flash Image Pairs

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You want to take a picture in a scene with low light. What do you do?

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How can we combine the strengths of both?

Techniques:
• ambient image denoising
• flash to ambient detail transfer
• white balancing
• continuous flash adjustment
• red-eye correction

Pair Acquisition

1. Focus on the subject, then lock the focal length and aperture.
2. Set exposure time $\Delta t$ and ISO for a good exposure.
3. Take the ambient image $A$.
4. Turn on the flash.
5. Adjust the exposure time $\Delta t$ and ISO to the smallest settings that still expose the image well.
6. Take the flash image $F$.

Denoising

Bilateral filter
• Removes noise while still maintaining edges
• Just applied to noisy ambient image $A$ (no use of flash image)

$$A_p^{\text{Bene}} = \frac{1}{k(p)} \sum_{p' \in \Omega} g_s(p' - p) g_r(A_p - A_{p'}) A_{p'}$$

where $k(p)$ is the weight based on spatial distance between pixels, and $g_r(A_p - A_{p'})$ sets the weight on the range based on intensity difference (edge-stopping).
Denoising

Joint bilateral filter
• uses the flash image $F$ instead of $A$ to compute the edge-stopping function

$$A^N_{p} = \frac{1}{k(p)} \sum_{p' \in \Omega} g_{d}(p' - p) g_{s}(F_{p'} - F_{p}) A_{p'}$$

Flash-To-Ambient Detail Transfer
• The joint bilateral filter cannot add detail that may be present in the flash image.

Flash-To-Ambient Detail Transfer
So, we compute a detail layer:

$$F^{Detail} = \frac{F + \varepsilon}{F^{Base} + \varepsilon}$$

$F^{Base}$ is computed using the basic bilateral filter on $F$.

And apply it to the denoised ambient image:

$$A^{Final} = (1 - M)A^N F^{Detail} + MA^{Base}$$
To solve this problem, we use a threshold-based shadow mask:

$$M_{\text{shad}} = \begin{cases} 1 & \text{when } F^{\text{Lin}} - A^{\text{Lin}} \leq \tau_{\text{shad}} \\ 0 & \text{else} \end{cases}$$

We also want to detect specular regions caused by the flash. To do this, we just look for luminance values in the flash image that are greater than 95% of the range of sensor output values.

Then, we merge the two masks and feather the edges.

White Balancing

- Think of the flash as adding a point light source of known color to the scene
- Illumination due to the flash only: $\Delta = F^{\text{Lin}} - A^{\text{Lin}}$
- Estimate the ambient illumination at the surface with the ratio:

$$C_p = \frac{\Delta}{A_p}$$

- Analyze this at all image pixels to infer the ambient illumination color $c$. 

Flash-To-Ambient Detail Transfer

Detecting Flash Shadows and Specularities

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White Balancing
White Balancing

White-balance the image by scaling each color channels as:

$$A_{WB}^p = \frac{1}{c} A_p$$

Continuous Flash Adjustment

• Convert Flash and Ambient images to YCbCr space and interpolate linearly:

$$F_{Adjusted} = (1 - \alpha) A + (\alpha) F$$

Red-Eye Correction

• Convert the pair to YCbCr space (decorrelates luminance from chrominance)
• Compute a relative redness measure:

$$R = F_{Cr} - A_{Cr}$$

• Segment the image into regions where \( R > r_{Eye} \)
• Look for seed pixels where

$$R > \max\{0.6, \mu_r + 3\sigma_r\} \text{ and } A_r < r_{Dark}$$

Red-Eye Correction

Summary

Techniques:
• ambient image denoising
• flash to ambient detail transfer
• white balancing
• continuous flash adjustment
• red-eye correction