Photometric Camera Calibration: Precise, Labless, and Automated with AutoLum

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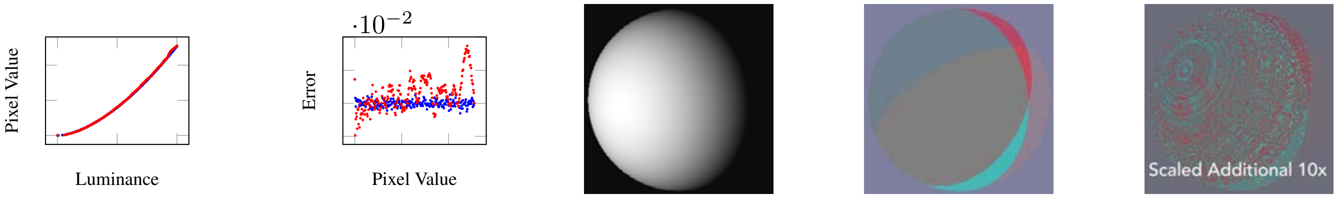

(a) *Estimated response curves, our method in blue, Debevec's in red*

(b) *Residuals for Estimated Photometric Response Curves*

(c) *Ground truth sphere*

(d) *Normal Error Map for Calibration by Debevec's Method*

(e) *Normal Error Map for AutoLum Calibration*

Figure 1: *(a) and (b) show our algorithm, "AutoLum", finds a more accurate photometric calibration than Debevec's method. When used in photometric stereo simulations, our calibration (e) leads to 1 order of magnitude less surface normal angular error than Debevec's (d).*

1 Introduction

Even cheap camera phones can sense finer changes in luminance than the human visual system ($0.2 - .5\%$ steps vs. $1 - 2\%$ JND), but noise and poor calibration limits their abilities to precisely measure light. This poster describes "AutoLum", our fully automatic, software-only method that finds a camera's photometric calibration, its "numbers-to-light amounts" table, with precision well beyond the camera's own quantization levels. This table captures each quantization step and reveals correctable non-uniformities that allow more accurate results for almost any graphics or vision task that relies on pixel-by-pixel light estimates. These include HDR light probes, environment maps, estimates of material transparency and translucency, BRDF and BTF, or any 3D scanning method that relies on "shape from shading". As shown in (Fig. 1), our method reduced angular errors in photometric stereo by 10x.

2 Method

Unlike prior approaches that fit smooth curves to hundreds of samples taken from tens of photographs of a fixed scene [Mann and Picard 1995; Debevec and Malik 1997; Mitsunaga and Nayar 1999; Robertson et al. 1999], AutoLum assesses millions of samples from thousands of photographs of a controlled display to compute individual camera quantization boundaries. Users simply aim the out-of-focus camera at the display in a dark room and AutoLum will compute, display, and photograph an adaptive series of test patterns constructed by 2-color ordered dithering. Dithering enables the uncalibrated display to emit finely-controlled light amounts in precise steps, while factor-of-two camera shutter-time adjustments allow the camera to control incident light in factor-of-two changes.

AutoLum begins by pairing the display maximum (1.0) with the nearest second pixel "color" slightly more than one factor of two darker. It then doubles the camera shutter time and dithers the display to find the 2-color pattern that holds the camera's average pixel value constant in a small vignetting free central region of the sensor. All intervening dither patterns then uniformly divide this power-of-two luminance range enabling extremely fine light source control.

AutoLum builds its calibration table by adaptive refinement. For each entry, it finds the two closest-bracketing light amounts for each of the camera's whole-pixel-values (e.g., the light values that produce camera outputs 12.95 and 13.01 that bracket "13"). We estimate the camera quantization power for every whole-pixel-value with a weighted average of the two bracketing light values.

Our method revealed errors in assumptions about cameras at the heart of previous methods such as linear RAW response, uniform pixels, and uniform quantization increments. Because AutoLum directly measures quantization boundaries with millions of samples, it does not make assumptions about the shape of the camera's photometric response function, but instead tolerates high noise during calibration, and corrects for many of the errors.

Detailed simulations confirmed that AutoLum can calibrate low-cost devices well because it does so under very noisy conditions with sub-quantization level error. We confirmed the method's accuracy with both real and synthetic camera experiments and repeated both with Debevec's method. In photometric stereo [Woodham 1980] , AutoLum's calibration reduced average surface normal angular error by more than 10x.

References

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