Evaluation of Radiometric Camera Response Recovery Methods

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Figure 1: *The response of a Canon EOS 550D is recovered with three methods (right) using the samples (middle) from the exposures (left).*

1 Introduction

The camera response function determines the relationship between the incident light on the camera sensor and the output pixel values that are produced. For most consumer cameras, this function is proprietary and needs to be estimated to create HDR images that accurately represent the light distribution of the captured scene. Several methods have been proposed in the literature to estimate this unknown mapping using multiple exposures techniques. In this study, we compare three of the most commonly used methods namely Debevec and Malik's [1997], Mitsunaga and Nayar's [1999], and Robertson et al.'s [2003] response curve estimation algorithms in terms of how precisely they estimate an unknown camera response.

2 Comparison

We implemented all three algorithms in C++ using the exact procedures outlined in the respective papers. We selected around 300 distinct sample positions from the uniform regions of the individual exposures. In that we had 9 exposures, this amounted to a total of 2700 samples. We ensured that we had at least one sample for every intensity level and the samples are not clumped together. A representative set of samples is shown in Figure 1. As Mitsunaga and Nayar's algorithm does not have a weighting mechanism to underplay the influence of under- and over-exposed samples, we discarded the samples outside the range $[5, 250]$ only for that algorithm.

The recovered response curves of a Canon EOS 550D using three of the studied algorithms are shown on the right of Figure 1. As this figure shows, the response curves are not only different from each other but they also deviate significantly from the sRGB gamma. To evaluate the fidelity of each algorithm, we devised the metric

$$\mathcal{E} = \sum_{q=1}^{Q-1} \sum_{r=q+1}^{Q} \sum_{p=1}^{P} \{ w(M_{qp}, M_{rp}) \left[g(M_{qp}) - R_{q,r}\, g(M_{rp}) \right] \}^2$$

where Q is the number of exposures, $w(x, y)$ is the weighting function, g is the inverse camera response function, M_{qp} is the intensity of pixel p in image q and $R_{q,r}$ is the exposure ratio between images q and r. This error metric relies on the idea that when pixels are linearized by using the inverse of the response curve, their ratios should be equal to the ratio of the exposure times which is known as the reciprocity principle. Thus, in an ideal setting this error term should be equal to zero. Here, the weighting function w controls the contribution of different intensity levels to the error term. We give the highest weights to middle of the intensity range and linearly decrease it toward the extremes. We give zero weight to very small and high values as these are the most unreliable parts:

$$w(x, y) = \begin{cases} 0 & \text{if } x \text{ or } y \text{ not in } [5, 250] \\ (x + y)/255 & \text{if } (x + y)/2 \leq 127.5 \\ (255 - (x + y)/2)/127.5 & \text{if } (x + y)/2 > 127.5 \end{cases} .$$

Method	Error	Performance (sec)
Debevec and Malik	5538.77	74.68
Mitsunaga and Nayar	11803.23	0.29
Robertson et al.	6145.13	8.39
sRGB assumption	77697.70	N/A

Table 1: *Comparison of the response recovery methods. Performance testing was made on an Intel Core i7 CPU at 3.20GHz.*

The error produced by each algorithm as well as their running times are listed in Table 1. We used 9 exposures shown on the left of Figure 1. Debevec and Malik's method yields the lowest error while Mitsunaga and Nayar's method produces the highest. However, all three methods induce a significantly lower error than the sRGB gamma. This underlines the importance of recovering the response of a camera for accurate HDR generation instead of relying on the sRGB assumption. The error produced by Robertson et al.'s method is similar to Debevec and Malik's which may be expected as their problem formulations are similar. We can observe an inverse relation between the fidelity of each method and their running times.

References

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