HDR - the impact of input parameters on the result for Debevec algorithm

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Abstract

Humans can perceive a much broader luminance range than cameras. HDRI methods merge multiple low dynamic range images into a single picture, addressing this problem. These methods are used in professional and even smartphone cameras.
This work examines optimal input parameters, including the number of images, their exposure times, and weighting functions using the Debevec-Malik method. Images were captured with varying exposures but constant sensitivity and aperture.
Multiple combinations of input parameters were investigated to create HDR images. These were evaluated for noise, color fidelity, and realism. The radiance map and camera response curve provided detailed information on image quality and dynamic range.
Each additional photo provides new scene information, potentially improving quality and reducing noise. However, benefits diminish after a certain point, so a smaller number of images can be used for faster processing.

Introduction

The human eye can perceive a very wide range of luminance, far exceeding the capabilities of common digital cameras. Although the eye can adapt to a large variety of light conditions, a single image taken with a regular camera will often fail to capture the full dynamic range of a scene with both very bright and very dark areas. To overcome this limitation, the technique of High Dynamic Range Imaging has been developed. Generating HDR images typically involves techniques such as exposure bracketing, where multiple photos are captured with varying exposure times and then combined to create a single HDR image. This approach has become widely adopted, being utilized not only by professional photographers but also by users of smartphones. By combining a sequence of images with varying exposure times, it is possible to capture a wider range of luminance values than that of a single frame. This is done by applying an appropriate weighting function to each input image, and then combining them into a single high dynamic range image, or radiance map.

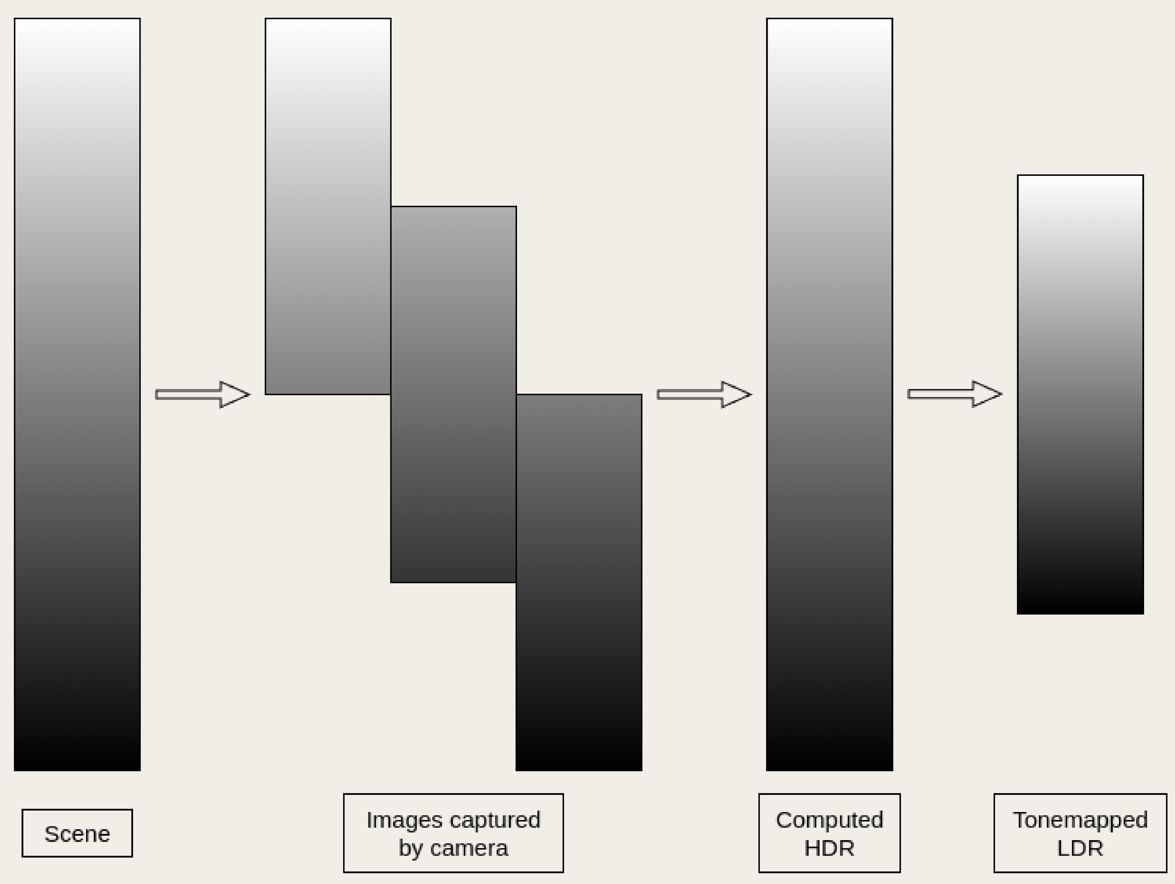

Figure 1. Diagram of HDR technique

Materials and Methods

The study used a stationary Nikon D40 camera on a tripod to capture 40 photos with 1/3 exposure steps, minimizing scene movement issues. Camera settings, except exposure time, were held constant.The article focused on analyzing a single indoor scene with varied lighting, partially examining other scenes. The camera generated RAW and JPEG files, with RAW data used in the experiments.The study investigated how input parameters impacted HDR image quality using the Debevec-Malik algorithm, comparing test HDR to a reference HDR. Metrics like relative error and SSIM were used to identify challenges.The research was conducted in Python and the colour-hdri library, with results stored in MongoDB and a viewer tool used to inspect the HDR images.

Figure 2. Comparision of real photo with tonemapped one - parameters for better showing indoor

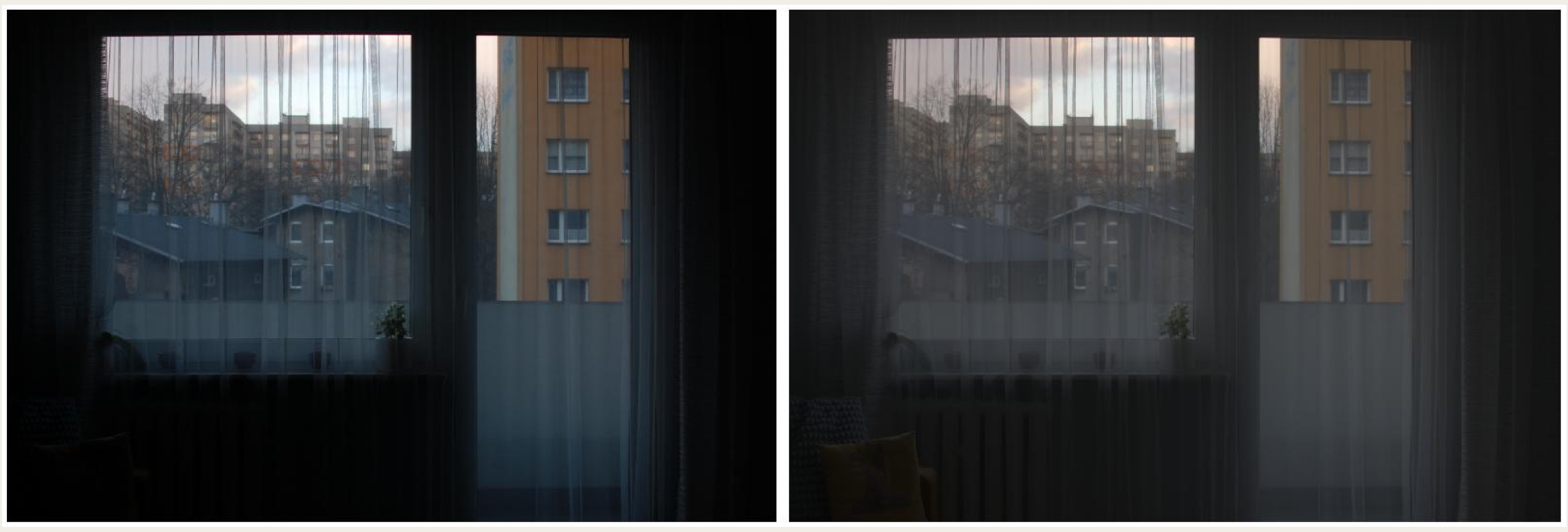

Figure 3. Comparision of real photo with tonemapped one - parameters for better showing outdoor

Experiments

The reference HDR image was created using a normal weighting function for the camera response curve and a truncated normal weighting function for the resulting HDR image. This truncation reduced the dynamic range by about 3 and 1/3 stops, but was acceptable given the large number of input images with a minimal step of 1/3 EV.
The study found that as the number of input images increases, the required exposure step can be reduced, from 4 EV for 2 images to 1 EV for 8 images. The calculated errors also decrease with more images, but visual assessment showed that 3 images provided excellent results without significant noise in the darker areas.
The linearity assumption for the camera response curve was found to be the best approach, performing better than reconstructing the curve from a small number of images. Additionally, the "hat" weighting function performed worse than other tested functions.

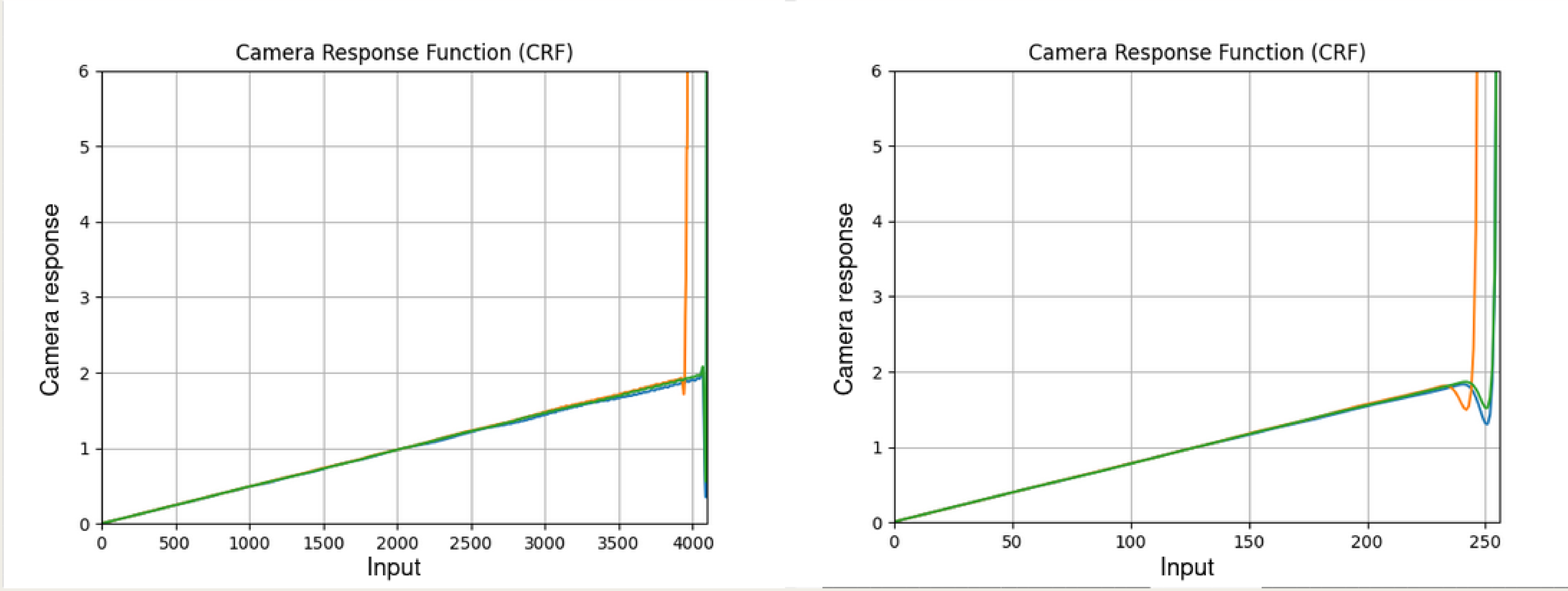

Figure 4. Calculated camera response function for RAW

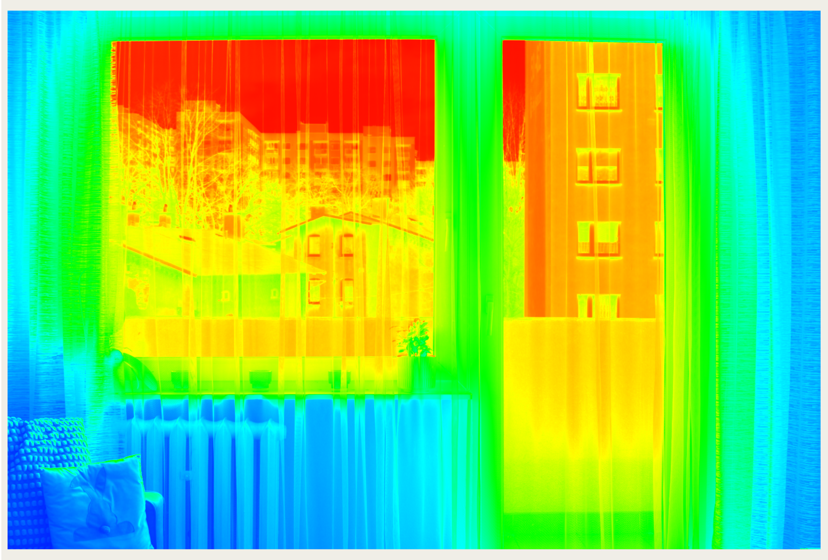

Figure 5. Heatmap of calculated HDR image

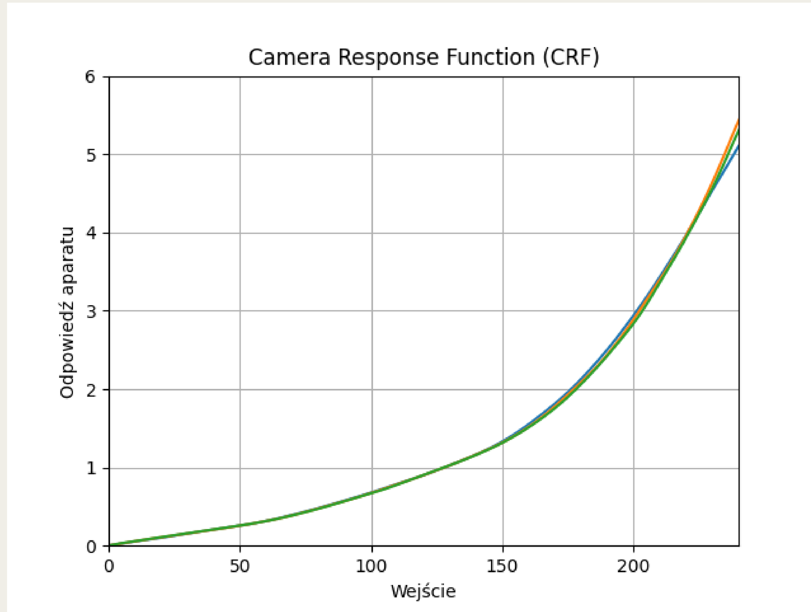

Figure 6. Calculated response function for JPEG files

The optimal number of images for the test scene is 3, as the gain above this is not significantly perceptible. The Clipped function requires minimal overlap of 1-2 EV between images, while other functions need up to 7 EV overlap to compensate for noise. The linearity assumption proved the best approach, outperforming reconstructed camera response curves. One tested weighting function, the "hat", performed significantly worse than others.
Furthermore, the researchers found that the Clipped function, despite being truncated too much, showed advantages in the results, allowing images to be processed together with a much larger step. Additionally, it was determined that the linearity assumption is the best possible approach, saving processing time and resulting in significantly lower standard deviation of relative error compared to reconstructed camera response curves.

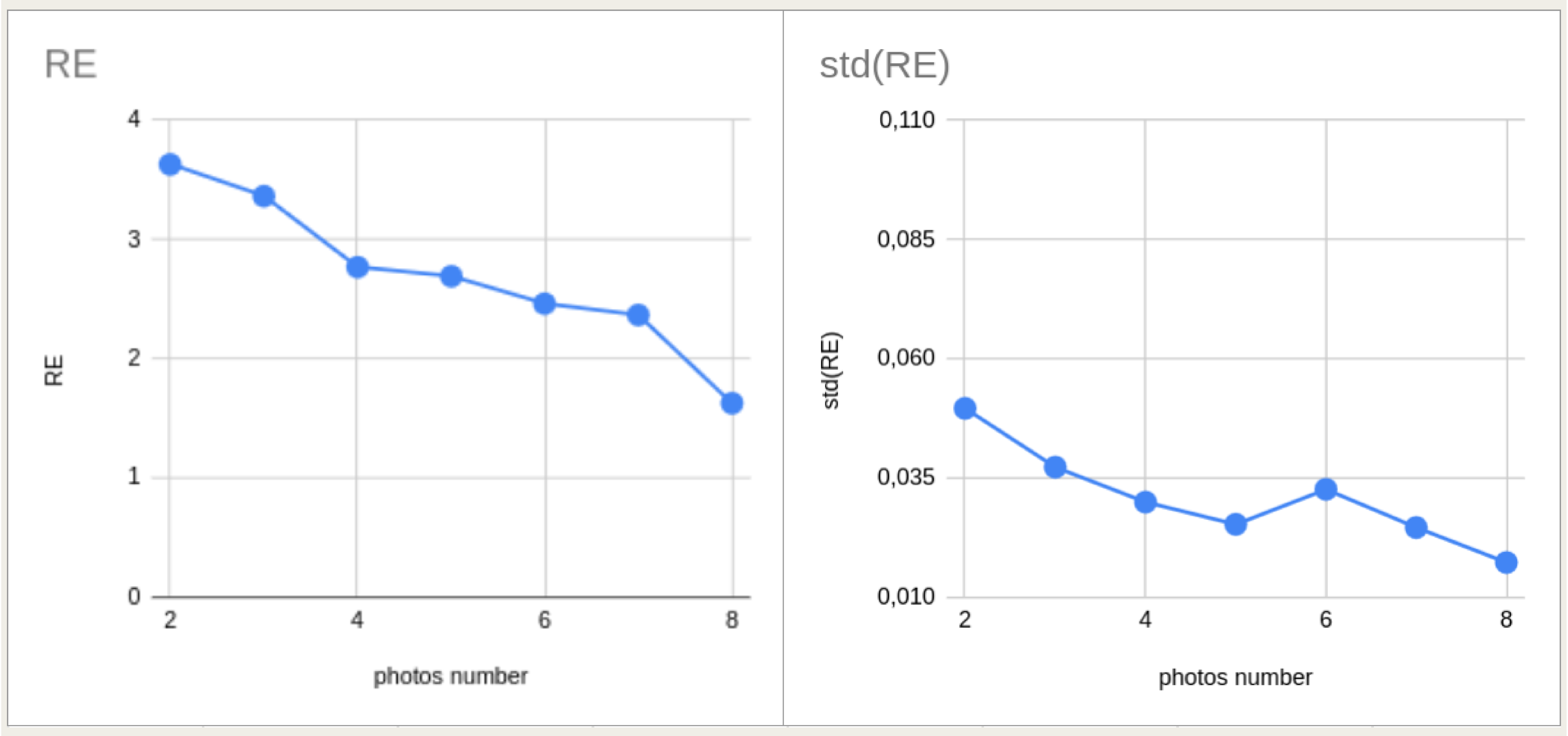

Figure 7. Chart for average RE and std(RE) metrics value for given number of photos

Future work

This paper could be expanded by comparing the Debevec-Malik algorithm to other HDR imaging techniques, such as the Robertson algorithm. Additionally, using a light meter to measure scene radiance and calibrate the camera could improve the accuracy of the results. Examining a wider range of scenes, both indoor and outdoor, with varying lighting conditions and dynamic ranges would provide more comprehensive insights. Exploring different weighting functions, including further investigation of the clipped function, and employing a single consistent camera response function across all HDR images, rather than deriving a unique function for each, are other potential avenues for future research.