HDR Image Deglaring via MTF Inversion with Enhanced Low-Frequency Characterisation

Alejandro Sztrajman Hongyun Gao Rafał Mantiuk

UNIVERSITY OF CAMBRIDGE

IOP Institute of Physics
imaging.org

Abstract

Accurate measurement of the Modulation Transfer Function (MTF) is crucial for high quality imaging, as it quantifies how well an imaging system reproduces both fine details and large-scale variations in brightness, which are essential for reducing blur and glare. However, traditional MTF estimation methods, like the slanted edge technique, often struggle to accurately capture the low frequency components of the MTF. To address this, we propose a novel optimisation-based MTF estimation method that uses the image of a disc-shaped light source. Our proposed method leverages a parametric model of the MTF, allowing for flexible representation of light spread patterns. Through optimisation, we fit this model to the observed light spread in the captured image, with a focus on achieving a precise characterisation of the low frequency component.

Image Deglaring via MTF

HDR images often suffer from glare, obscuring details and reducing image quality.

Figure 1. Image with glare.

Traditional methods for deglaring are based on the estimation of the Modulated Transfer Function (MTF) of the camera, which can be computed as the FFT of the Point Spread Function (PSF) of the camera. The MTF essentially quantifies how accurately details on different spatial scales are captured, as a function of the spatial frequency.

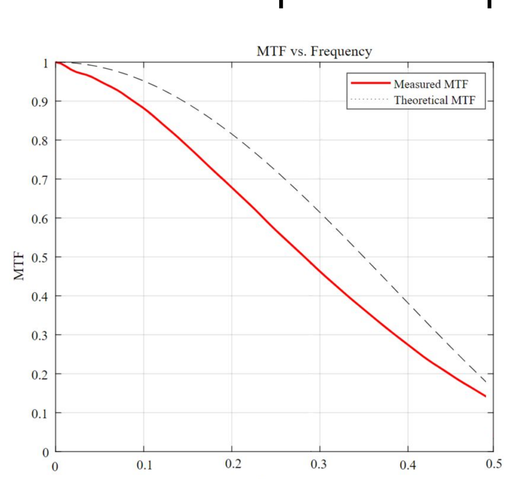

Figure 2. Example of a typical camera MTF vs frequency curve.

A degraded image due to glare often exhibits a reduced response in both low and high frequencies of the MTF. However, traditional methods struggle to accurately characterise low-frequency components in the MTF, leading to an incomplete glare removal.

MTF Estimation

Our method for camera MTF estimation is based on the simple capture setup shown in Figure 3. A light source is enclosed within a black box, with a circular aperture through which the emitted light is directly captured by the camera.

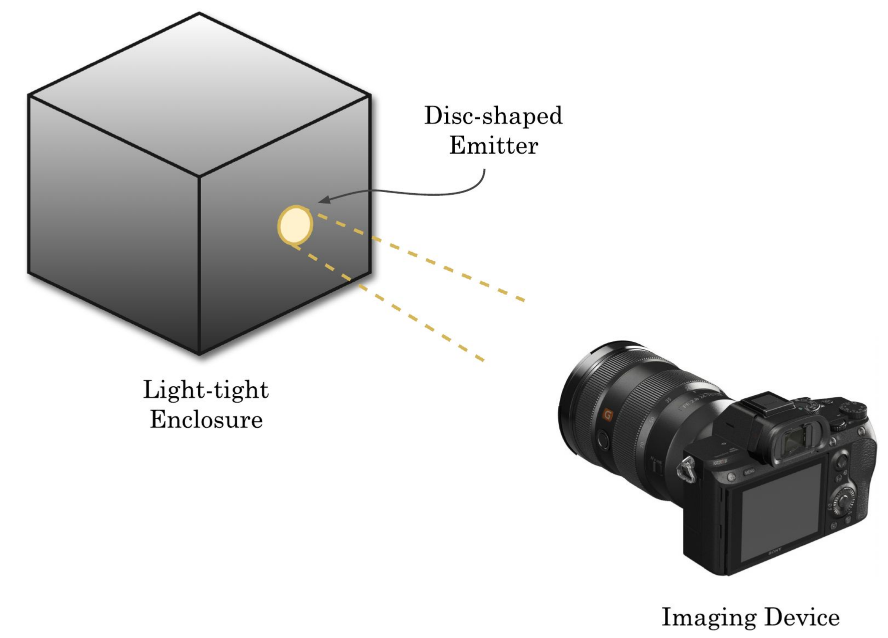

Figure 3. Diagram of the capture setup for low-frequency MTF estimation

Within this setup, the captured image intensity I(x, y) can be modelled as the convolution of the disc-shaped light source, O(x, y), with the PSF of the camera, H(x, y):

$$I(x,y) = O(x,y) * H(x,y)$$

Values of I(x, y) exceeding a fixed threshold represent the direct light from the source, while values below are attributed to glare. This allows us to delineate the glare-affected region for the purpose of MTF estimation. In the frequency domain, the convolution operation becomes an element-wise multiplication.

$$\mathcal{F}\{I(x,y)\} = \mathcal{F}\{O(x,y)\} \cdot \mathcal{F}\{H(x,y)\} = O(\xi_x,\xi_y) \cdot M(\xi_x,\xi_y)$$

with ξx and ξy spatial frequencies. The MTF ranges from 0 to 1, with 1 indicating perfect reproduction of a particular spatial frequency and 0 indicating complete attenuation. Finally, we can express our prediction of the image with glare as:

$$I'(x,y) = \mathcal{F}^{-1}\{O(\xi_x,\xi_y) \cdot M(\xi_x,\xi_y)\}$$

which, for a given MTF, allows us to compute a prediction of the glared image.
In order to estimate the MTF of the camera, we use an optimisation-based approach. We model the MTF as a parametric sum of three exponentially decaying functions:

$$M(\xi) = p_0 e^{-\xi^2/p_1} + p_2 e^{-\xi^2/p_3} + p_4 e^{-\xi/p_5}$$

where $\xi = \sqrt{\xi^2 x + \xi^2 y}$, and p0 to p5 are parameters that control the amplitude and decay rate of each exponential term. The values of the parameters are estimated by optimising a differentiable implementation of the image formation equation, minimising the difference between the captured image I(x, y) and the predicted one I′(x, y):

$$\mathcal{L} = \frac{1}{N}\sum_i^N \left|\log\left(1 + I'(x_i,y_i)\right) - \log\left(1 + I(x_i,y_i)\right)\right|$$

By solving the minimisation problem, we obtain the optimal set of parameters for the MTF model. This estimation of the MTF can then be leveraged for image deglaring.

Results

Figure 4 compares the MTF curves obtained using the slanted-edge method (blue) and our optimisation-based approach (red). Noticeable discrepancies in the low-frequency region are consistent with the limitations of the slanted-edge method in capturing this frequency range. As the spatial frequency increases, both methods converge to similar MTF values.

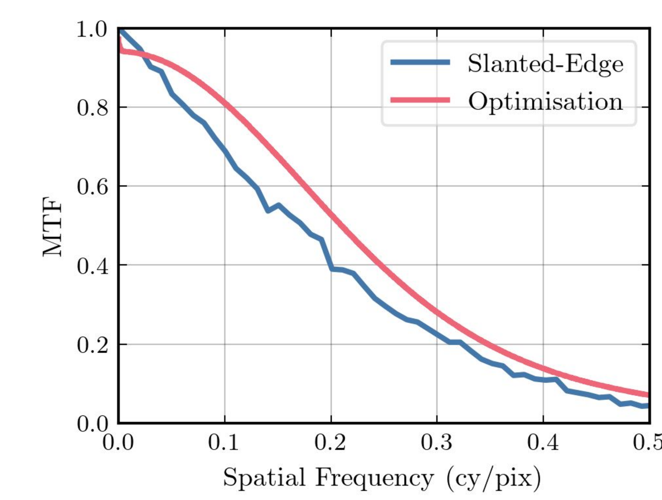

Figure 4. MTF vs spatial frequency for slanted edge and optimisation estimation methods.

Figure 5 shows the application of our proposed MTF measurement approach in image deglaring compared to the slanted edge method. The left panel shows the original image, exhibiting noticeable glare that washes out details and reduces colour saturation. The center panel (slanted edge), reveals over correction artefacts, with overly dark pixels on the boundaries of the zoomed-in letters and ruler ticks. Our method in the right panel achieves a more balanced result: glare is effectively suppressed without introducing artefacts or excessively darkening the edges.

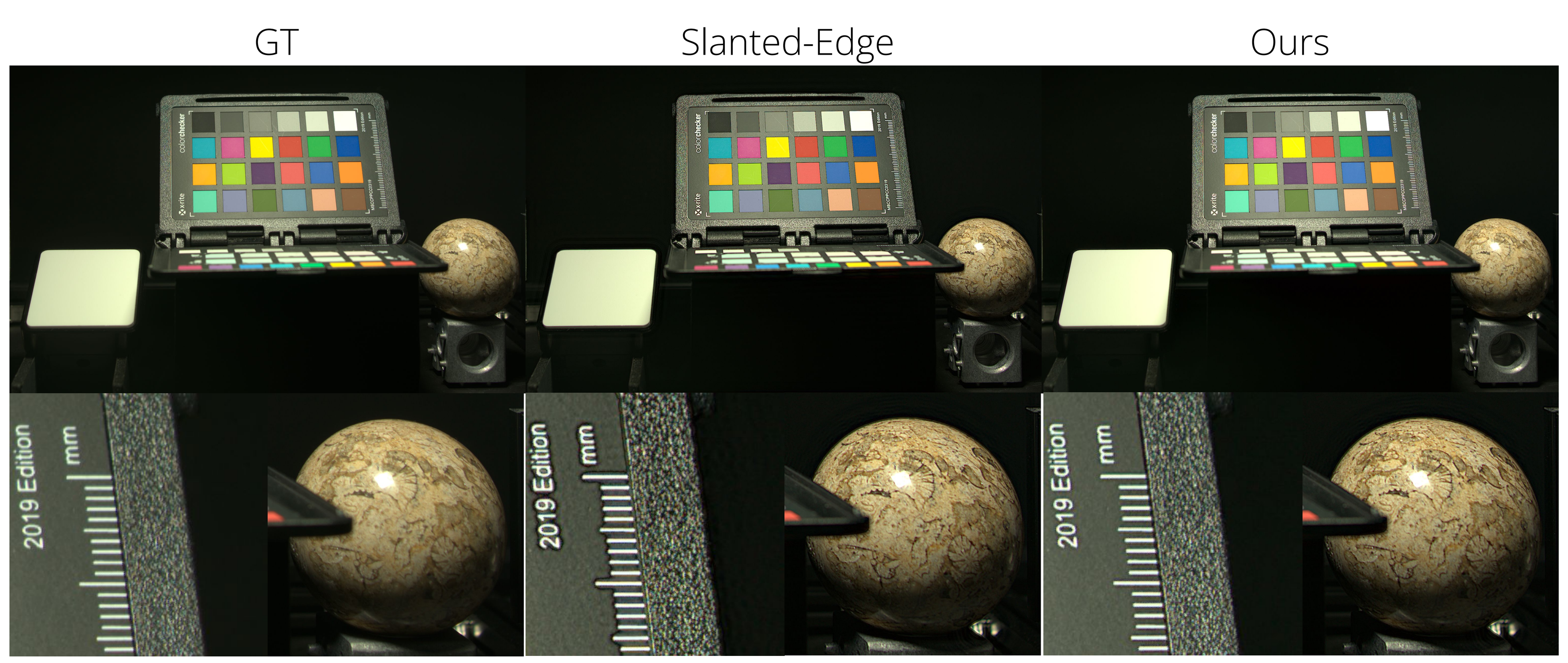

Figure 5. Left: Original image. Center: Image deglared with slanted-edge MTF measurement. Right: Image deglared with optimisation-based MTF measurement.

In Figure 6 we show the deglaring of a simple scene, with a single C-shaped emitter, using slanted-edge and our method for MTF estimation. An illustrative plot can be seen in Figure 7, where we show the pixel intensity for a scanline of the C-shaped emitter image, confirming that our MTF estimation leads to a larger reduction of the glare around the emitter, in comparison with the slanted-edge estimation.

Figure 6. Top-Left: Captured image I(x, y) of C-shape with glare. Top-right: Image deglared by slanted-edge method. Bottom: Image deglared with our method.

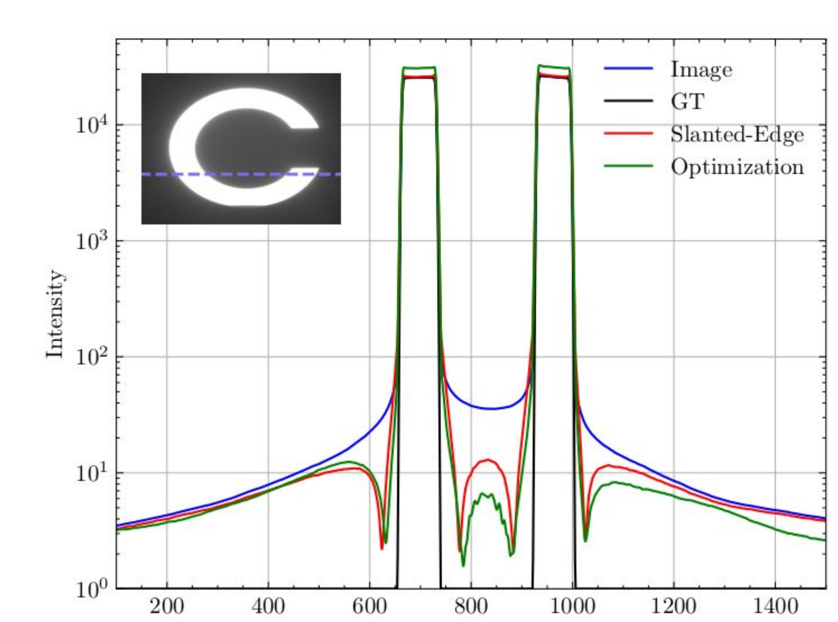

Figure 7. Intensity of pixels (log-scale) across a horizontal scanline in the images from Figure 4, showing the original and deglared images obtained by Slanted-edge and optimization (ours) methods.