Film Emulation Using Dynamic Range and Tone Mapping [TENTATIVE]

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Motivation

When taking an image with a camera, the range of light and dark values it can represent at once is its dynamic range, with values outside of this range being completely dark or completely light, thus possessing no visual information. Dynamic range is a common complication for computational photography and image processing, as scenes with a wide range of light and dark (such as a sunset) become difficult to photograph properly with a consumer camera, as its limited dynamic range will make it challenging to to get bright areas and dark areas properly exposed to make a compelling image.

One popular approach to dealing with this problem is high dynamic range (HDR) photography, in which a series of computational techniques are used to generate an image with a dynamic range much higher than that of a single input photo. There are many approaches to creating an HDR image, with Deep Learning becoming an increasingly popular area, but the most widely used approach is image composition. In this method multiple images of the same scene are taken at different exposures, and then digitally combined to create a single image where areas of under/over exposure are filled in by the full set of images.

The result, however, is not yet a compelling photograph. Most displays and printing mediums are not designed for HDR images, and thus the wide range of exposure information will make the image seem low-contrast and dull. To correct this a technique called tone mapping is used, in which an HDR image is normalized and adjusted to match the contrast needs of displays while preserving the details and balance developed in the composite. In this process it is possible to replicate the exposure response of different film stocks, allowing us to use HDR imaging to emulate the look of color film photographs using digital cameras.

From this, our project will consist of two primary components: registration of multiple exposure images to form an HDR image, and tone mapping to emulate film photographs from HDR images.

Technical Background

There are a variety of algorithms for HDR compositing, but a popular choice and one available in OpenCV is the Debevec algorithm, that leverages a camera response curve to combine exposures – the response curve being the camera's sensitivity to different amounts of light depending on exposure settings. By taking this into account the method works to reconstruct the original light levels of the scene unaffected by the camera's response curve.

For the tone mapping we effectively conduct the opposite of the HDR composite production, in which we get the response curve to a chosen color film stock, and apply it to the HDR composite to get an image representative of a film stock's response to the original scene. This work can be supplemented by the addition of glare and diffusion (with one such example coming from Debevec's paper) to more accurately recreate the look that a film stock would produce when exposed to the scene.

As a final note we plan to use the RAW files from a Sony digital camera, to give us the most exposure and image data possible.

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Methodology

Our proposed methodology for HDR film emulation is as follows,

- Collect a series of photographs of a scene with a wide range of light values (such as a sunset) at different exposure settings.

- Register the photos to fix any discrepancies in camera movement across the photos.
- Calculate an image response curve for the photos and compare it to the known response curve of the camera.
- Using the response curve and the registered images, use the Debevec algorithm to calculate an HDR composite.
- Recreate the image response curves of a film stock of choice.
- Use tone mapping with the film response curve (also known as a histogram transformation) to get a fill emulated image.

The folowing components are stretch goals,

- Apply the methods of Ward Et al. to simulate the glare and contrast sensitivity of the film stock.
- Use edge detection on a radiance map of the HDR image to simulate halation – a tinted glow in overexposed film images.
- Use the color spectrum response of the film stock to modify the color response of the image to better match that of a film image.

The majority of this work can be completed using OpenCV, with the assistance of some custom generated functions to allow for the tone mapping. The result of these steps should be a compelling and accurate emulation of a film image.

Measures of Success

To evaluate the effecvtiveness of our film emulation we will emply qualitative and quantitative assessments.

Qualitative Evaluation

We will perform visual comparisons between our processed images and reference images to assess the effectiveness of our film emulation approach. These comparisons will focus on certain analog imaging properties such as **[insert some film image properties]**. By examining these specific attributes, we can evaluate how successful our algorithm reproduced the distinctive aesthetic properties of film. Finally, a successful film emulation implementation would not have any unintended artifacts such as ghosting from the registration process or unusual transitions between light and dark.

This statement requires citation [1]. This statement requires multiple citations [1, 2]. This statement contains an in-text citation, for directly referring to a citation like so: Jones and Smith [2].

Quantitative Evaluation

Using OpenCV and NumPy, we will calculate the dynamic range of our processed images to measure how well the HDR functionality has been implemented. In addition to calculating the dynamic range we will create difference maps comparing our normalized HDR images to the original input images. This will demonstrate our algorithm's ability to preserve information while adding the film characteristics. Ideally, we should be able to compress our HDR image back to the original digital image exposure ranges.

An additional metric to evaluate our HDR composition process and image set will be to compare the image response curve generated by the Debevec algorithm to the known response curve of our chosen film stock and digital camera to ensure that our method is accurately compositing exposures.

Goals

The primary objective of our project is to develop algorithms that emulate the distinctive characteristics of photographic film and increase the dynamic range of digital images. Through this work, we aim to deepen our understanding of film response characteristics particularly how film cameras interpret light intensity in comparison to digital sensors. By implementing film processing techniques we will create algorithms which address the limitations of digital image capturing using modern photographic technology and create visually appealing images.

Potential Challenges

First, working with RAW image data presents significant complexity since OpenCV does not directly support RAW images. We will need to implement preprocessing techniques so that the image is in a format compatible with OpenCV while ensuring the full dynamic range from the digital sensor is preserved. Another challenge we foresee is accurately reproducing film response characteristics. Film has a non-linear response light which is complex to accurately mathematically model. Finally, sensors in digital cameras vary and different camera sensors will result in different response curves. This may require device-specific algorithms so that our film emulation remains accurate.

References

[1] J. M. Smith and A. B. Jones. *Book Title*. 7th. Publisher, 2023.

[2] A. B. Jones and J. M. Smith. "Article Title". In: *Journal title* 13.52 (Mar. 2024), pp. 123–456. DOI: 10.1038/s41586-021-03616-x.