Reconstruct a Hyperspectral Image from a Single Shot

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1 Motivation and Background

Hyperspectral information is useful in many applications such as material classification, remote sensing, biomedical diagnosis, and image segmentation [1]. However, most modern cameras only have three color channels and don't have a mask or collimating optics. It seems hard to obtain full spectrum from a single shot by a three-color-channel camera. However, if we add some dispersion to the image formation process, which means incoming light of different wavelengths will form slightly different images on the sensor, we can make use of the dispersion and solve the spectrum from it. The dispersive imaging system therefore performs as an encoder. I would like to explore the decoding algorithms to reconstruct hyperspectral images.

The challenge in this problem is, suppose dispersion causes images from different channels to shift by some pixels, images of different wavelengths can overlap with each other. The spectral information is lost in overlapping. However, the key insight is there are large spectral gradients on edges. So it's promising to recover precise spectral information from the edges. In addition, usually the spectrum is piecewise smooth, which indicates we can reconstruct the whole hyperspectral image from rich spectral information on edges.

2 Related Work

2.1 Filter-based hyperspectral imaging

A straightforward way of obtaining hyperspectral images would be using a set of band-pass filters[2, 3]. This comes in two different ways. One way is to apply a filter in the camera and switch to a different filter for each shot. However, this method requires more than one shot and the mechanical filter switching motion can cause blur. Another way is to replace the Bayer color filter array with another filter array composed of filters of more bands. However, the more bands we have, the more mosaic the image would be. Besides, filters with a narrow band can have very low transmittance, which can decrease the signal-to-noise ratio.

2.2 Mask-based hyperspectral imaging

A typical mask-based hyperspectral imaging system is implemented in [4]. The idea is to use a prism to produce spatial dispersion. To avoid overlapping by different wavelength bands, they place an occlusion mask to sample the scene so that there will be no overlapping between neighboring sampling pixels' spectra. This method can provide a high spectral precision, but the resolution can be very low.

2.3 Estimating spectrum based on dispersion

In this project, I would like to implement the hyperspectral image reconstruction algorithm published in [1]. As discussed in the background section, this method does not require a mask or collimating optics, and only needs an ordinary three-channel camera and a dispersive element such as a blazed grating or a prism. This method is cheap in its implementation and can produce a high-resolution hyperspectral image from a single shot.

3 Project Overview and Milestones

Basically, in this project, I would like to implement the algorithm published in [1]. The goal is to reconstruct hyperspectral images from RGB images captured by an ordinary camera with additional spatial dispersion. To simplify the procedure without loss of generality, I would arbitrarily assign a dispersive image formation model for the raw data acquisition process and hyperspectral imaging reconstruction process in my project to avoid the tedious camera calibration process. I would use a public hyperspectral image dataset [5] to test my implementation.

1. Week7: Read and understand the algorithms described in [1].
2. Week8: Implement the algorithm on simple input images such as an image of a ColorChecker.
3. Week9: Fine-tune the parameters in the algorithm and test it on a larger dataset.
4. Week10: Prepare the poster presentation and final project report.

References

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