20p-C4-5

Computational Hyperspectral Imaging

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1. Emerging Area: Computational Imaging

Computational imaging apparatus are modern systems that consist of generalized optics and image processing capability. The term 'computational imaging', also known as 'computational photography', describes the emerging field of optical systems in which an image is not formed by a lens and simply sampled onto the detector. Rather, the process of image formation is facilitated by both the power of the optical elements and the computational processing of the sampled light signal. Such an imaging system integrally incorporates optics, optoelectronics, and signal processing. These systems can be optimized to greatly increase the performance of the imaging apparatus that utilizing solely traditional optics. By introducing computation into spectral imaging, breakthroughs could be achieved in imaging speed, resolution and spectral accuracy.

2. Recent Progresses on Hyperspectral Imaging

At present, there are mainly three different kinds of techniques that have been proposed to realize a hyperspectral imager. The first kind of spectrometer is based on scanning an image spatially, capturing full spectral data sequentially. This kind of devices obtains images by integrating a dispersive means (a prism or a grating) in an optical system, and has the drawback of having the image analyzed per points (whiskbroom scan) or per lines (push broom scan). These techniques are widely used in remote sensing and satellite. The second kind of technique is based on scanning an image spectrally, capturing full spatial information sequentially. These devices consist of optical band-pass filters. Spectrum of a static scene can be captured by switching filters in front of a grayscale camera [1]. The key idea for these two kinds of techniques is trading time information for spectrum. They both have accurate spectrum capturing due to direct measurement. However they are incapable of capturing dynamic scenes and have low efficiency in term of light gathering power.

The third kind of technique can be described as taking a 'snapshot', which means capturing all spectral information with certain spatial resolution at single exposure. This technique is usually integrated with computational post-processing. Typical methods include: integral field spectrograph, Fourier transform imaging spectrometer, computed tomography imaging spectrometer (CTIS), image replicating imaging spectrometer (IRIS), coded aperture snapshot spectral imager (CASSI), and prism-mask based hybrid camera system. Taking CTIS and CASSI for example, instead of directly measuring the spectral data of each scene point, they treat hyperspectral imaging as a reconstruction problem. They regard the two dimensional (2D) spatial information plus one spectral dimension as a 3D data cube. CTIS reconstructs the 3D data cube from a set of 2D projections [2], and CASSI takes multiplexed 2D projections of the 3D data cube using a specially designed aperture, then reconstructs the whole spectral data cube through coding and decoding the optical field [3].

Inspired by computational imaging strategy, we proposed a series of systems aiming at capturing hyperspectral video with both high spectral and spatial resolution. Our prism-mask based imaging system was proposed for direct, real-time capture of hyperspectral video [4]. It is able to achieve high spectrum precision and the tradeoff between spectral and spatial resolution is easily fulfilled. However, since this prism-mask system sacrifices considerable spatial resolution, the utility of their captured data for video analysis applications is limited. In order to compensate for this, a hybrid camera imaging system is built to accomplish spectral video capturing with higher spatial resolution [5]. This system records two video streams: one high spatial resolution RGB video and one low spatial resolution hyperspectral video. Then, after the video frame registration and synchronization steps, a spatial-temporal spreading of the co-located spectral/RGB information is implemented; and thus video with both high spatial and spectral resolution can be produced. Furthermore, we have also proposed a dynamic mask based system to sample the spectral data-cube more efficiently and more adaptive to the scene content [6]. Based on all the aforementioned work, we have achieved efficient and effective acquisition of hyperspectral video. Various applications such as environmental monitoring, security surveillance, machine vision, and scene modeling can be envisioned by these systems.

3. Conclusions

Computational imaging has brought new opportunities for hyperspectral imaging and video capture. It is driven toward a higher resolution both in spatial, spectral and in temporal domain. The future of spectral capture may rely on the development and realization of the recent progresses of sparse theory.

Acknowledgements

We would like to express sincere thanks to the Project of NSFC (No. 61327902 & 61120106003).

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