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Developments towards a filter wheel hyperspectral camera for planetary exploration

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Abstract

The benefits of hyperspectral imaging in remote sensing applications are well established and it is now routinely exploited in terrestrial applications. However the restrictions imposed on mass and power consumption and the extreme operating conditions encountered in extra-terrestrial environments have limited its widespread use for planetary exploration. Instead multispectral camera systems with typically 10-12 discrete filters are employed, providing only coarse spectral information. By exploiting the properties of interference filters off axis it is possible to obtain additional spectral information. Recent advances in filter technology have made it possible to develop a simple and lightweight wide angle hyperspectral camera employing a filter wheel. The theory of operation and early test results from a prototype camera system are presented.

1. Introduction

By combining optical spectroscopy and digital imaging, multispectral and hyperspectral imaging provide a versatile remote sensing technique capable of enhancing subtle contrasts and classifying minerals remotely by their spectral signatures. A key application of the multispectral cameras on previous planetary exploration rovers has been mapping the geology in proximity to the rover as a means of identifying potential science targets for further study. Typical multispectral cameras employed in such applications include the Panoramic Camera (PanCam) instruments on the NASA MER rovers [1] and the future ESA-NASA ExoMars rover [2] which employ filter wheels with 10 and 12 filters respectively covering the range 440-1000nm. As minerals have few distinctive spectral features in this range, diagnostic spectral features can easily be missed, even with a carefully selected filter set [3]. Clearly a hyperspectral imager would be highly desirable to ensure that all diagnostic features in the spectral range are detected but mass, power consumption and complexity prohibit the use of most hyperspectral imaging technologies in such applications. By exploiting properties inherent to interference filters a simple and lightweight filter wheel based hyperspectral imager is under development.

2. Method

2.1 Thin film filters off axis

Thin film filters work on the principle of optical interference – constructive interference gives a high transmission in the pass band and destructive interference gives a high optical density elsewhere. The thin film stacks used in such filters are optimized so that the optical path lengths through the films give rise to the required interference. The optical path length is dependent on the angle of incidence of the light passing through the filter. The transmission band of interference filters therefore changes as the angle of incidence of the light is varied. The shifted centre wavelength (λ) for a given angle of incidence (θ) is related to the wavelength at normal incidence (λ_0) and the effective refractive index of the thin film stack (n_{eff}) by (1).

$$\lambda = \lambda_0 \cdot \sqrt{1 - \frac{\sin^2(\theta)}{n_{eff}^{\,2}}} \qquad (1)$$

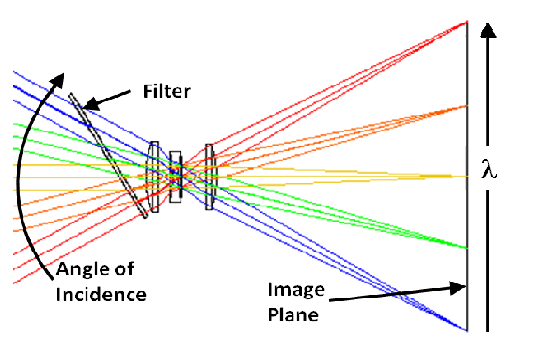

Figure 1. A ray diagram for a thin film filter mounted at an angle in front of a wide angle lens.

2.2 Wide angle cameras with filters

When a filter is mounted in front of an endocentric lens, the angle of incidence of the light passing through the filter will vary across the field of view. From (1) it can be seen that the wavelength passing through the filter will decrease as the angle of incidence increases. The shift in wavelength will be symmetric about the centre of the field of view in a well aligned system. If however the filter is mounted in front of the lens at an angle equal to half the field of view of the camera, the symmetry will be broken and the angle of incidence will increase from zero at one side of the field of view up to a maximum at the other side. The wavelength of light reaching the image plane will therefore decrease as the angle of incidence increases across the field of view as shown in Figure 1.

A filter wheel containing a set of suitable filters [4] mounted at an angle in front of a wide angle camera could be used to obtain hyperspectral images. A sequence of images would be taken with each filter in turn as the camera is panned across the object of interest to capture image segments over a range of wavelengths. The image segments could then be used to reconstruct an image hypercube.

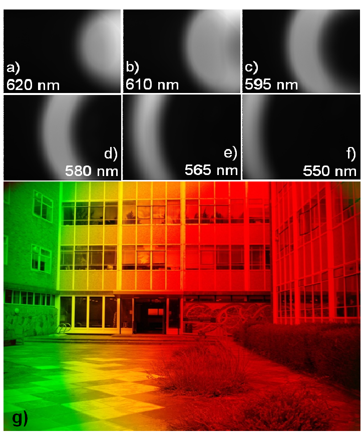

Figure 2 a – f) Calibration images from the prototype camera at different wavelengths. g) Color image taken through the tilted filter showing the dispersion.

3. Results

A prototype camera system is under development to test the practicalities of this method. A single Semrock VersaChrome [4] filter covering the spectral range 550 – 620 nm has been mounted at 30˚ in front of a 60˚ field of view camera. Calibration images shown in Figure 2 a-f have been taken by pointing the camera into an integrating sphere illuminated with tunable monochromatic light from a grating monochromator. The images clearly show that different regions of the image are exposed to different wavelengths. A color photo taken through the filter (Figure 2 g) illustrates the dispersion of wavelengths across the field of view.

4. Conclusions

The limitations on mass and power imposed on hardware used for planetary exploration has limited scientific cameras to multispectral capabilities with around 12 wavelengths. A hyperspectral camera is under development for planetary exploration which exploits the properties inherent to interference filters. Such a camera could increase the accuracy of mineral classification and potential for science target identification in future planetary exploration missions.

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