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A SWIR HYPERSPECTRAL IMAGING SYSTEM FOR ART HISTORY AND ART CONSERVATION

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Abstract:
PRISMS is a portable hyperspectral imaging system designed for high resolution, in situ, remote imaging of paintings at inaccessible heights from the ground level. It currently operates from 400nm to 1700nm to provide detailed conservation monitoring, material identification and to assist art historical investigations for wall paintings. The system can be fitted with a variety of imagers to operate in the visible, near infrared and short wave infrared at close range and remotely. This talk will focus on the SWIR (short wave infrared) hyperspectral imager and its applications in art history and art conservation. The filtering system in the SWIR is based on an AOTF (acousto-optical tunable filter) system developed by Gooch & Housego that operates between 900nm and 1700nm which provides fast switching between the spectral bands as well as full flexibility in terms of central wavelength and bandwidth of the filters. Applications in imaging of underdrawings (preparatory sketches) beneath oil paintings and identification of paint materials will be presented.

Keywords: hyperspectral imaging system, AOTF, remote imaging, multispectral imaging, colour, near infrared, short wave infrared, wall painting, pigment identification

INTRODUCTION

Scientific imaging has been an integral part of 'technical examination' ever since the beginning of conservation science. In the last 15 years, research in the application of imaging science to art conservation has flourished as a result of the achievements in other fields where non-invasive imaging is in high demand.

Multispectral and hyperspectral imaging are non-invasive imaging techniques capable of recording the spectral reflectance per pixel of an object with accuracy comparable to a spectrometer but with the added advantage of being able to capture the spectral reflectance of millions of points simultaneously. The spectral information obtained for a painting can be used for non-invasive pigment identification, for the monitoring and examination of any deterioration and for the accurate colour rendering in any given illumination. Multispectral imaging in the visible spectral range has been applied to art conservation for at least 15 years, however, it is only recently that it has gone from being research led to being in demand by conservators [1]. Multispectral/hyperspectral imaging is flexible and can be used for accurate colour, infrared and fluorescence imaging.

Based on experience with high resolution, precision colour and spectral imaging of easel paintings in studios, we have developed a portable colour and multispectral camera system that is light-weight, flexible and without any cumbersome mechanical structure for *in situ* high resolution colour and spectral imaging of wall paintings [2, 3]. This is the first instrument to be able to image paintings at inaccessible heights *in situ* from ground level to produce not only high resolution colour images but also multispectral images. The recording, monitoring and non-invasive examination of wall paintings in grotto sites, tombs and buildings are particularly important since these paintings are extremely vulnerable. Traditionally, imaging of wall paintings at high resolution requires either scaffolding or some heavy and cumbersome mechanical structure to lift the camera to the upper parts of a wall or ceiling. We present here the latest developments on the instrument focusing on the SWIR imager.

INSTRUMENTS AND METHODS

PRISMS (Portable Remote Imaging System for Multispectral Scanning) is designed for the in situ, high resolution imaging of wall paintings or any painting hang at heights that is difficult to access without any mechanical structure such as scaffoldings [1, 2]. PRISMS is portable and can operate from the ground level and achieve sub-mm resolutions of up to 25 pixels/mm. It consists of a small telescope, a VIS/NIR (400-900 nm) multispectral imaging system, a SWIR (short wave infrared: 900-1700 nm) hyperspectral imaging system. The VIS/NIR multispectral imager is a simple, low budget instrument consisting of a filter wheel with 10 filters of 40nm bandwidth and a CCD camera. The SWIR hyperspectral imager is based on an AOTF (Acouto-Optic Tunable Filter) system that is software controlled to provide wavelength switching and bandwidth selection. To improve the flexibility of PRISMS, it is upgraded to take advantage of the modular design which consists of a filter system (filter wheel or AOTF), a digital camera (Si or InGaAs detector depending on the wavelength of interest) and focusing optics (various lens for close range imaging or small reflector telescopes for remote imaging) mounted on either an Altitude/Azimuth telescope mount or X-Y linear translation stages. The system is automatically controlled by a laptop to change filters, to focus, to move the pointing direction and to capture images. Resolutions of at least 5 pixels per mm are achieved for working distances of 1m to 25m, and sub-millimetre resolutions can be achieved for distances below 100m. For both close range and long distance imaging, the whole system stays at ground level during operation. The system can be dismantled and packed in a suitcase with the heaviest component weighing 10kg.

In the following section, we evaluation the capabilities of the AOTF based SWIR imager of PRISMS.

RESULTS

AOTF allows rapid and flexible choice of the central wavelength as well as the bandwidth and transmittance of the filters. The AOTF is designed such that one of the diffracted (filtered) rays is optimised to give the best image quality. In order to separate the optimised diffracted ray from the zero order beam, it is necessary to allow the beams to travel a sufficient distance before the detector. The beam is folded to minimize the size of the imager. Examples of measured filter response produced from the AOTF system are shown in Fig. 1.

The images obtained were calibrated using the usual calibration procedure for multispectral imaging which involves corrections for the thermal noise of the digital camera (dark correction), corrections for the inhomogeneity of the illumination and the pixel-to-pixel gain variation of the digital camera (flatfield correction), and finally corrections for the difference in throughput between the spectral bands (spectral correction). For dark correction, dark frames are taken with the lens/telescope cap on for the same amount of exposure time as the image to be corrected. Flatfield frames can be taken with a matt white or grey card at the same position as the target to be imaged through the same filter. An image of the target is calibrated by subtracting the dark frame and dividing by the normalised (i.e. divide the frame by the average pixel intensity), dark corrected flatfield frame. Spectral calibration is achieved by imaging a spectral standard (e.g. a Labsphere Spectralon white standard) through all the filter channels. The final calibrated image cube gives the spectral reflectance at each pixel. There is no need for any special spectral reconstruction algorithm to be applied as the spectral reflectance of paint is relatively smooth and a cubic spline interpolation is sufficient to recover the visible spectrum for medium spectral resolutions of 50nm (or higher resolution). Given the flexibility of the AOTF, it is efficient and convenient to image at low resolution first and to re-image a part of the spectrum with suspected narrow spectral features at higher spectral resolution (e.g. Fig. 2).

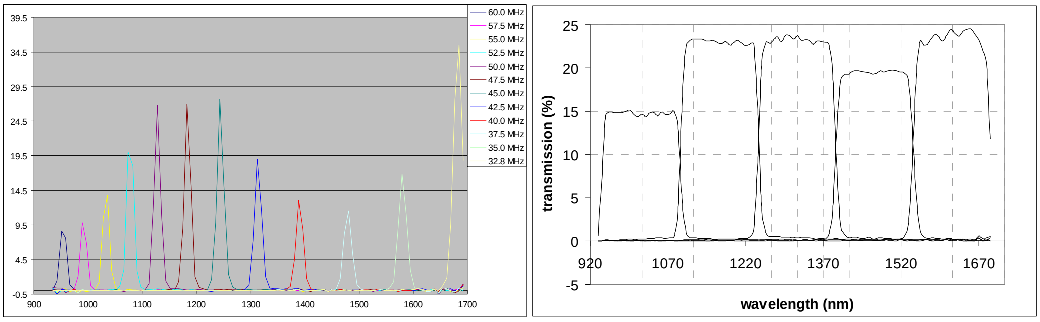

Figure 1. *Measured filter transmission using the AOTF system. LEFT: A set of filters over the full spectral range of 900-1700nm with the narrowest bandwidth of ~10nm; RIGHT: A set of filters with bandwidth of 150nm.*

Figure 2 shows the spectral reflectance of azurite mixed with linseed oil measured with PRISMS using the VIS/NIR filter wheel system and the SWIR AOTF system using the 150nm bandwidth filter set given in Figure 1. The flexibility in the choice of central wavelength and bandwidth with the AOTF means that the spectrum could be measured at different sampling resolutions when necessary. For example, a higher sampling rate and narrower band filters can be used to better resolve the absorption line around 1500nm in the azurite spectrum.

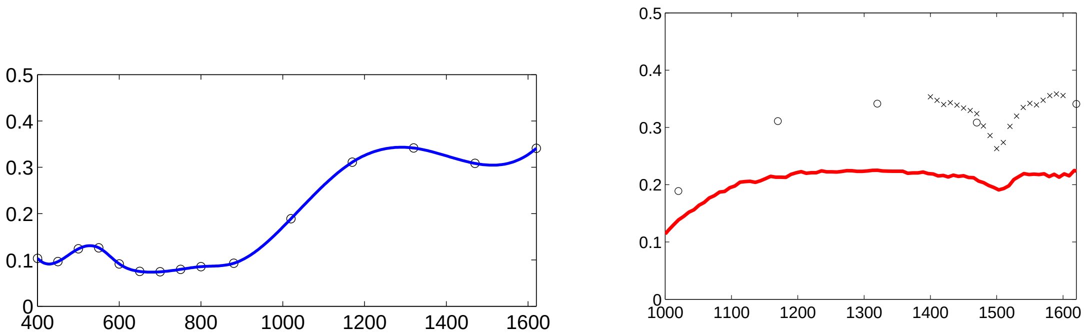

Figure 2. *LEFT: Spectral reflectance of azurite measured with PRISMS using the VIS/NIR imager with 10 filters from 400nm to 880nm and the SWIR imager with the AOTF tuned to 5 filters centred at 1020nm to 1620nm with bandwidth of 150nm. The open circle gives the data points and the blue line is a cubic spline interpolation from the data. RIGHT: SWIR spectra of azurite obtained with AOTF tuned to 150nm bandwidth filters (open circle) and AOTF tuned to 10nm bandwidth filters for high spectral resolution imaging of the absorption feature (crosses); the red spectral line corresponds to a spectrum of azurite (different sample) measured with a Polychromix DTS1700 spectrometer.*

It has long been recognised that most paint are more transparent in the infrared than in the visible and hence infrared imaging can reveal the preparatory sketches (underdrawings) under the paint layers. Figure 3 shows an example of SWIR images of azurite and Prussian blue paint over underdrawings made of a variety of material from charcoal to red ochre. It is interesting to note that the narrow band (1545-1695nm) SWIR image in Fig. 3 reveals more of the underdrawings than a broadband (900-1700nm) SWIR image (middle image in Fig. 3). The SWIR hyperspectral imaging system has the potential of providing better images of underdrawing than a broadband InGaAs camera.

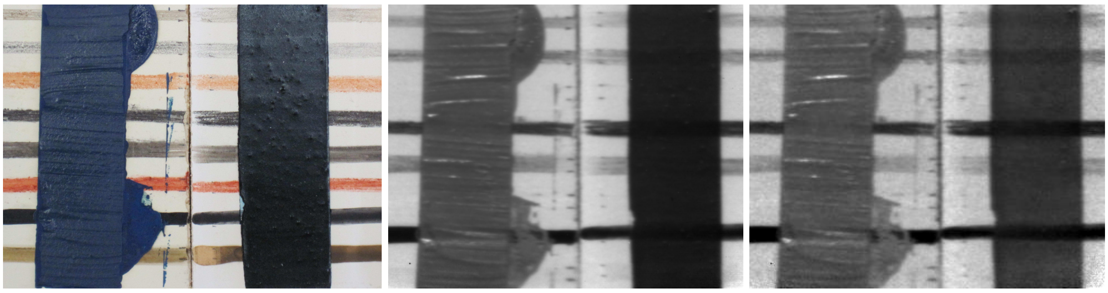

Figure 3. *LEFT: A colour image of a test panel with two vertical bands of paint (azurite in oil on the left and Prussian blue in oil on the right) over a set of horizontal drawings using a variety of drawing material commonly used for preparatory sketches for paintings. MIDDLE: A SWIR image of the test panel over the full spectral range of 900-1700nm. RIGHT: A SWIR image of the test panel centred at 1620nm over a narrower bandwidth of 150nm.*

CONCLUSIONS

The new AOTF based SWIR imager is capable of rapid and flexible spectral imaging that enhances the pigment identification capabilities of PRISMS as well as providing better images of underdrawings. PRISMS is the first instrument to be able to image both small objects such as manuscripts at close range and paintings at inaccessible heights *in situ* from ground level at high resolution to produce not only colour but hyperspectral images over the UV/VIS/NIR and the SWIR spectral range. The possibility of *in situ* spectral imaging without the need for cherry pickers or scaffolding means long term savings and increased ease/frequency of monitoring. The portability of the system means flexibility and easy transportation such that it can be taken to remote sites to image large paintings *in situ* from ground level. In museums, this means the possibility of imaging at high resolution very large paintings. The remote high resolution spectral imaging system provides conservators with an invaluable tool for examining and monitoring the conditions of paintings.

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