DEVELOPING AND TESTING OF A LOW-COST SPECTROMETER FOR ROBOTICS APPLICATIONS.

S. W. Hobbs[1], D.J. Paull[1], and J. D.A. Clarke[2], School of Physical, Environmental and Mathematical Sciences, University of New South Wales Canberra, Australian Defence Force Academy, Northcott Drive, Canberra, Australian Capital Territory 2600, Australia, 2Mars Society Australia. P.O. Box 327, Clifton Hill, VIC 3068, Australia.

Introduction: Optical spectrometers have become invaluable instruments for understanding the physical properties of light for the past two centuries [1] Spectroscopes have also been carried on board planetary science missions, including stationary and mobile landers to the surface of Mars [2]. Terrestrial precursors of these missions also included versions of spectroscopes in order to provide proof of concept prior to designing flight versions of the hardware. These have included the Rocky series of rovers that preceded the Sojourner rover mission, and a terrestrial-based rover used to test operations for MER [3].

A drawback of most spectroscopes has been their cost, with even budget instruments costing well over the $1000 mark. This precludes their use for low budget applications and experimentation, though in recent years there has been development efforts to produce low cost spectrometers made from off the shelf or readily available materials [4, 5, 6]. One particular example, developed by Public Lab, is intended to place the science of spectroscopy into the hands of everyday people and to promote interest in science [7]. In this current work we tested a custom built spectrometer based on the Public Lab design [7] using minerals found on Mars for which spectra could clearly be identified, as well as chlorophyll-based vegetation to assist in calibration. We performed reflectance measurements on these minerals using a tungsten based light source as well as natural sunlight and compared the results with similar measurements derived from a Spectral Evolution SR/SM-3500 series spectrometer. The SR/SM 3500 is sensitive to wavelengths between 350-2500 nm with a spectral resolution of ~1.5 nm [8].

Methods: The spectrometer was constructed from balsa wood and used a section of DVD for a diffraction grating. A Raspberry Pi NOIR camera with a pixel resolution of 2592 x 1944 was used as an image sensor, and the instrument was controlled by a Raspberry Pi. We chose this camera because of its higher imaging resolution as well as sensitivity to near infrared (NIR) compared to a webcamrecommended in the Public Lab design, greater ability to control exposures, as well as its ability to be controlled by the Raspberry Pi. The latter point was important for us as we intended this spectrometer to be used on small ground robots, such as Mars Society Australia's Little Blue rover (Fig. 1) that was trialled in Arkaroola in 2014 [9].

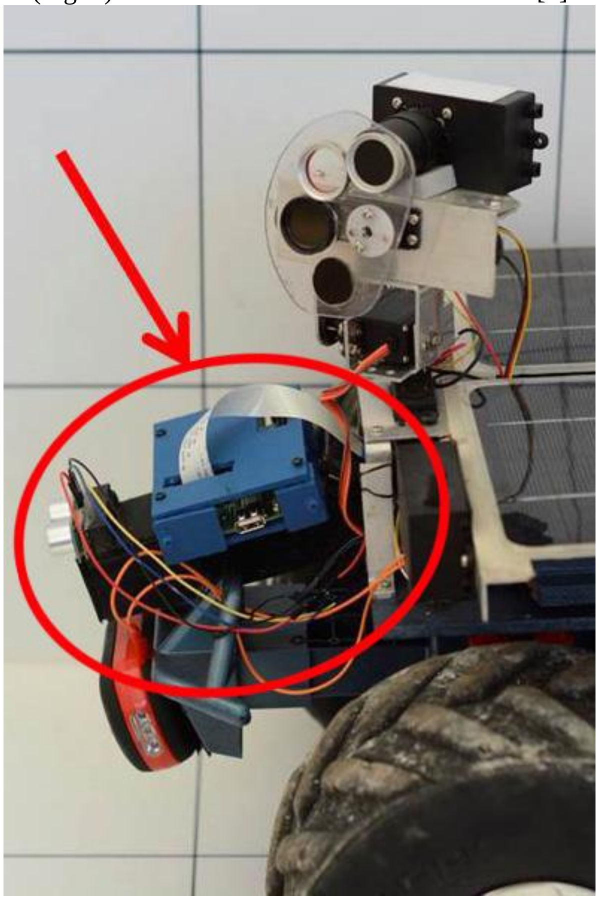

Figure 1. Custom made spectrometer (circled) mounted on a Mars Society Australia robot chassis.

Testing of the instrument was achieved by illuminating mineral using a Miniblitz studio flash as a standardised light source. The Miniblitz provided a continuous spectrum between 400-1000 nm as measured by the SR/SM-3500 series spectrometer used as an experiment control. Spectra were then sampled and then calibrated with dark current and white card exposures to remove sensor noise and influences from the light source [4, 10]. A second series of experiments was performed using direct sunlight as the illumination source. Additional wavelength calibration was conducted using a compact fluorescent lamp in a similar manner to previous research [10, 11].

Results: Fig. 2 shows a comparison of a leaf spectra obtained with our instrument in direct sunlight

(Fig. 2A) compared with the control spectrometer (Fig. 2B). The sampled spectra (blue line) plus a 31 step moving average result to reduce noise (red line) is shown in Fig. 2A. Although our spectrometer was able to distinguish between ~415-775 nm we found the spectra to be very noisy compared with the laboratory instrument, particularly in the NIR region. The leaf provided the best response, with the high reflectance of NIR exhibited by photosynthetic vegetation clearly visable (Fig. 2A, B). We assess noise in the spectra to be a function of sensitivity of the NOIR camera to NIR. We noted a dropoff in sensitivity with responses at 770 nm to be ~25 % of the highest sensitivity value, centering on 470nm. This sensitivity response is typical of CMOS sensors [10, 11], requiring increased exposure times to collect sufficient light for useful spectra.

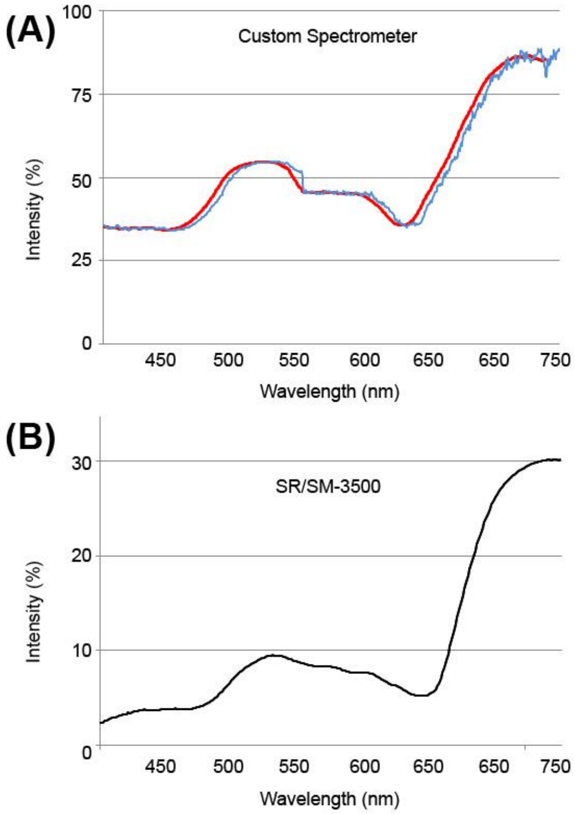

Figure 2. Intensity vs wavelength plots of a green leaf for **(A)** our custom made spectrometer and **(B)** the control instrument.

Additionally we noted differences in intensity between our spectrometer (highest value 90%, Fig. 2A) and the SR/SM-3500 (highest value 30%, Fig. 2B), probably caused by differences in dynamic range of the 8 bit NOIR camera sensor and the control instrument.

Discussion: Our work on a low cost, custom built spectrometer is ongoing. Our instrument is capable of sampling spectra in the visible-NIR range and initial results look promising. We did find the limited dynamic range of the sensor, plus the low sensitivity to NIR wavelengths to create sensitivity issues in our sampled spectra, particularly darker toned samples, where long camera exposures were required. These factors, as well as as possible interference caused by stray internal reflections, has produced noise within spectral responses (Fig. 2A). In a future iteration of the spectrometer we will be incorporating baffles within the instrument tube to remove the effects of internal reflections. We are also investigating the feasibility of using a monochrome sensor in a future design, allowing for greater radiometric sensitivity.

Acknowledgements: The authors would like to thank Dr Yagiz Sutcu for his assistance in the spectrometer project. The authors would also like to gratefully acknowledge the work done by Public Lab in developing an open source spectrometer.

References: [1] James J. (2007). *Cambridge University Press*. [2] Soderblom L.A. and Bell III J.F. (2008) *Cambridge University Press*. [3] Anderson R.E. et al. (2006). *Mars Analog Res*. [4] Veras G. et al. (2009) *Talanta 77*, 1155–1159. [5] Anzalone G. C. et al. (2013) *Sensors 13*, 5338-5346. [6] Divya M. and Raj Kumar E.R. (2013) *Int. Jour. Eng. Res. Tech.*, 2, 2930-2934. [7] Public Lab website (2015), http://publiclab.org/, downloaded 8/12/2015. [8] Spectral Evolution SR/SM 3500 Series Manual (2013). [9] Hobbs S.W. et al. (2014). *14^{th} ASRC Conf.* [10] Dominec F. (2010) *Czech Technical University, Prague*. [11] Rasooly A. and Herold E. (2105) *Meth. Mol. Biol.*, vol 1256, 1344–1345.