Institution: Aberystwyth University

Unit of Assessment: 11 - Computer Science and Informatics

Title of case study:

Planetary Exploration Based Camera Technology for Precision Agriculture Applications

1. Summary of the impact

The Space Robotics unit is heavily involved with the ESA/Roscosmos 2018 ExoMars rover mission, and is responsible for the radiometric and colourimetric calibration and image processing for **two** of the ExoMars science cameras during mission operations. Camera emulators have been built which has led to novel hyperspectral camera technology being developed. A terrestrial aerial version of this camera has been deployed in an unmanned aerial system (UAS) used for advanced remote sensing for precision agriculture applications. Impact on practitioners in this application area has emerged together with economic impact via Welsh Government funding. The ExoMars related research has led to impact in the area of society, culture and creativity.

2. Underpinning research

The Computer Science Space Robotics unit at Aberystwyth is focused upon advanced robotics and computer vision for space and planetary exploration. The group was involved with the Stereo Camera System (SCS) instrument onboard the ESA 2003 Mars Beagle 2 Lander [3.1], and due to the expertise gained, now has key roles within the future ESA/Roscosmos 2018 ExoMars rover mission. The unit has Co-Investigator status for both the international ExoMars Panoramic Camera (PanCam) [3.2], and CLose UP Imager (CLUPI) instruments. PanCam incorporates (Visible-VIS and Near Infrared-NIR) multispectral cameras [3.3], whilst CLUPI is a high resolution Foveon detector based camera. The group's responsibilities include the radiometric and colourimetric calibration for both PanCam and CLUPI, and processing the captured image data during the mission to generate scientific region of interest data, and natural-colour image products [3.4]. The instruments require in situ calibration targets on the rover during the mission, and these are being built by the unit. The application of advanced computer vision and machine learning based methods to autonomously identify science targets from the captured image data [3.5] is an ongoing research area for the unit.

The Beagle 2 lander work involved calibration of the robotic arm and the development of modelling/visualisation tools that would have provided the high-level arm motion command data during the surface mission. The SCS was part of the arm payload, and the Aberystwyth unit were responsible for the SCS geometric calibration prior to launch in 2003 [3.1]. Whilst the Beagle 2 mission did not realise the results that were hoped for, it did nevertheless provide the Aberystwyth unit with invaluable robotic and computer vision expertise that enabled key camera instrument roles to be won in open international competition for the next ESA (exobiology) mission to Mars in 2018 called ExoMars.

The Aberystwyth involvement with the ExoMars 2018 PanCam and CLUPI instruments has led to new on-Mars camera calibration target technology, and the design, and implementation of the Aberystwyth Radiometric and Colourimetric Image Processing Pipeline (RCIPP) software [3.4]. This work has been funded by STFC [3.7], the UK Space Agency [3.8], with additional contributions from two EU funded FP7 projects: Planetary Robotics Vision Ground Processing (PRoVisG) [3.9], and Planetary Robotics Vision Scout (PRoViScout) [3.10].

To design, develop and test the new Aberystwyth calibration targets and RCIPP software led to the unit building the Aberystwyth University PanCam Emulator (AUPE) which functionally mimics the detector, optics and filter wheel elements of the eventual flight instrument. It was the development of AUPE that led us to consider how we might design a hyperspectral camera instrument for future planetary exploration missions. As a consequence, the Aberystwyth unit developed the idea of a relatively low-cost, low-mass, robust and reliable hyperspectral camera which exploited the angle

dependence of interference filter transmission bands.

In open competition, an Ocean Optics "BlueOcean" development grant was awarded to Aberystwyth in 2011 to develop a camera prototype [3.11]. This was based on a windowing 'push-broom' data collection method, and the unit developed the camera calibration and image processing algorithms required to de-convolve the combined spatial/spectral data captured by the camera. This work led to the realisation that a terrestrial aerial version of the prototype could be developed given the low-mass, low-power, robustness and 'push-broom' aspects of the camera. Working with Environment Systems Ltd. and Callen-Lenz Associates Ltd., the Aberystwyth unit has developed a new multispectral aerial camera system which offers significant performance improvements over other aerial cameras, and it is this work that has given rise to a number of impact areas.

The research was carried out by a unit at Aberystwyth, including Prof. Dave Barnes (PI) (01/03/1999), Dr. Mark Neal (01/09/1997), Dr. Fred Labrosse (01/09/2000), Dr. Martin Wilding (03/01/2005), Dr. Dave Langstaff (01/04/1997), Dr. Changjing Shang (01/03/2011), Dr. Laurence Tyler (01/10/2007), Dr. Stephen Pugh (01/10/2008- 20/12/2012), and Aberystwyth research technicians.

3. References to the research

[3.1] Barnes, D., Phillips, N., Paar, G., Beagle 2 Simulation and Calibration for Ground Segment Operations, In *7th International Symposium on Artificial Intelligence, Robotics and Automation in Space (i-sairas 2003),* Nara, Japan, May19-23, 2003.

[3.2] Griffiths, A., Coates, A., Jaumann, R., Michaelis, H., Paar, G., Barnes, D., Josset, J-L., Context for the ESA ExoMars Rover: the Panoramic Camera (PanCam) Instrument, *International Journal of Astrobiology*, Vol. 5, Issue 03, July 2006, pp. 269-275, 2006. DOI: 10.1017/S1473550406003387.

[3.3] Claire R Cousins, Matthew Gunn, Bryan J Prosser, Dave P Barnes, Ian A Crawford, Andrew D Griffiths, Lottie E Davis, Andrew J Coates. Selecting the Geology Filter Wavelengths for the ExoMars Panoramic Camera Instrument. *Journal of Planetary and Space Science*, 71(1), 247-253, 2012. DOI: 10.1016/j.pss.2012.07.009. REF2 submitted.

[3.4] D. Barnes, M. Wilding, M. Gunn, S. Pugh, L. Tyler, A. Coates, A. Griffiths, C. Cousins, N. Schmitz, A. Bauer, and G. Paar. Multi-Spectral Vision Processing for the ExoMars 2018 Mission. In *11th Symposium on Advanced Space Technologies in Robotics and Automation (ASTRA 2011)*, ESA/ESTEC, Noordwijk, The Netherlands, April 2011.

[3.5] Mark Woods, Andy Shaw, Dave Barnes, Dave Price, Derek Long, Derek Pullan, Autonomous science for an ExoMars Rover-like mission, *Journal of Field Robotics*, Vol. 26 Issue 4, pp 358-390, April 2009. DOI: 10.1002/rob.20289. REF2 submitted.

[3.6] Gunn, M., Barnes, D., Cousins, C., Langstaff,. Tyler, L., Pugh, S., Pullan, D., Griffiths, A., A method of extending the capabilities of multispectral interference-filter cameras for planetary exploration applications. Proc. *2nd Annual Academic Sponsored Hyperspectral Imaging (HSI) Conference*, Glasgow, 16th-18th May 2011.

Key Research Grants:

[3.7] D. Barnes. Stereo wide-angle cameras for the ExoMars panoramic camera instrument - Part A, (2008 to 2010), STFC. £130K

[3.8] D. Barnes. Stereo wide-angle cameras for the ExoMars panoramic camera instrument - Part B, (2010 to 2013), UK Space Agency. £124K

[3.9] D. Barnes. EU FP7 PRoVisG: Planetary Robotics Vision Ground Processing, (2008 to 2011). Total EU Contribution to Aberystwyth: €259K.

[3.10] D. Barnes. EU FP7 PRoViScout: Planetary Robotics Vision Scout, (2009 to 2012). Total EU Contribution to Aberystwyth: €237K.

[3.11] M. Gunn, D. Langstaff, D. Barnes. Ocean Optics Inc - Blue Ocean Competition Award, Phase I, (2011). Total $10K.

4. Details of the impact

Impacts on practitioners and on the environment: Callen-Lenz Associates Ltd is a leading aviation consultancy and operations company with significant experience in the operation of Unmanned Aerial Systems (UAS) in civilian airspace. Environment Systems Ltd. is a leading environmental and geographic intelligence consultancy, and is at the forefront of developments in mapping and modelling of remotely sensed space and airborne data. These two SMEs jointly developed Project URSULA (supported by the Welsh Assembly Government) which involved unmanned aerial systems (UAS). URSULA (UAS Remote Sensing for Use in Land Applications) was a 2-year research and development programme to explore the potential for advanced remote sensing in land applications, primarily in high input arable farming [5.1]. As a result the UAS technology combined with multi-spectral aerial cameras is being used to drive improvements in managing agricultural practices such as the use of fertilisers, pesticides, invasive weed mapping and crop disease and stress detection. The Aberystwyth developed low-cost, low-mass, robust and reliable multispectral aerial camera has undergone UAS deployment trials with Environment Systems Ltd. and Callen-Lenz Associates Ltd., and returned outstanding results that are a step-change in spatial and spectral resolution when compared to commercially available camera systems [5.2], [5.3].

Economic Impact: There is no UAS deployable multispectral aerial camera on the market with a performance equivalent to the Aberystwyth system. So much so that Environment Systems and Callen-Lenz Associates have worked with the Aberystwyth unit to commercialise and exploit the Aberystwyth multispectral aerial camera technology. The two companies have in March 2013 spun out URSULA Agriculture Ltd., a joint venture company, to take the Project URSULA R&D to market and to commercially exploit the opportunities presented by UAS and imaging technologies within precision agriculture both in the UK and overseas export [5.4]. URSULA Agriculture Ltd. is responsible for marketing the Aberystwyth multispectral aerial camera [5.4]. Environment Systems, Callen-Lenz Associates, and URSULA Agriculture Ltd. are well positioned to understand the potential world-wide UAS multispectral camera market, and recent activities have led to new investment funding being sought in 2013 from the agriculture and investment communities, together with further support from Welsh Government (via a Smart grant). This venture capital and R&D funding of **£1-2m** is sought to deliver rapid growth and new jobs in the UK, and progress towards this goal has been achieved via a Welsh Government Academic Expertise For Business (A4B) grant being awarded [5.2], [5.3], [5.4].

Impacts on society, culture and creativity: The developed Aberystwyth PanCam instrument emulator together with the EADS Astrium Ltd. ExoMars development rover was selected via competitive proposal submission to be show-cased at the Royal Society Summer Science Exhibition from 30/06/2008 to 04/07/2008. The stand was entitled "Exploring the Solar System: mankind or machine?", and over four thousand visitors attended the exhibition [5.5], [5.6]. The event provided a unique opportunity for members of the public to interact with Aberystwyth scientists, the Bridget rover and the Aberystwyth PanCam emulator, and to ask questions about our work. Our PanCam instrument emulator together with the EADS Astrium ExoMars development rover was filmed by the BBC undergoing Mars mission operations trials at Clarach Bay, Wales, UK. The filming was for the BBC Coast Programme, Series 6, Episode 5 entitled "Wales - Border to Border", which was first shown on BBC2 on 10/07/2011 with an audience of 2.27 million viewers [5.7]. The program has been repeated a total of six times on BBC2 including 12/07/2011 with an audience of 2.34 million viewers [5.7], and on 10/06/2012 with 1.99 million viewers [5.7].

5. Sources to corroborate the impact

[5.1] Project URSULA Web Page: http://www.projectursula.com/. Last accessed 04/06/2013.
[5.2] Letter from the Director of Callen-Lenz Associates Ltd.
[5.3] Letter from the Director of Environment Systems Ltd.
[5.4] Letter from the Director of URSULA Agriculture Ltd.
[5.5] Review of the Summer Science Exhibition and Soirées 2008, The Royal Society of Arts..

[5.6] Royal Society Web Page: http://royalsociety.org/summer-science/2008/. Last accessed 04/06/2013.
[5.7] Broadcasters' Audience Research Board (BARB) web page: http://www.barb.co.uk/. Last accessed 04/06/2013.