AUPE – A PANCAM EMULATOR FOR THE EXOMARS 2018 MISSION

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1. ABSTRACT
This paper discusses the development of AUPE (Aberystwyth University PanCam Emulator), which has been developed as an emulator of the Panoramic Camera (PanCam) instrument that is to form part of the ESA/Roscosmos ExoMars 2018 mission. AUPE has been utilised at a number of field sites in the scope of ESA, EU-FP7 and national space research programs, and also at several UK field sites. These locations have each provided unique challenges for the hardware and software, which has resulted in the evolution of two generations of AUPE. This paper presents the design decisions, the lessons learned, and also discusses the solutions adopted for the current AUPE system.

2. INTRODUCTION
PanCam [1] has been designed to obtain high-resolution monoscopic images with approximately 5° field of view, along with multi-spectral stereoscopic images with approximately 34° field of view, from atop the ExoMars rover’s mast. The PanCam instrument is being developed to fulfil the digital terrain mapping requirements of the mission, along with a number of scientific functions through the use of multi-spectral filters. The scientific goals of the PanCam, being the primary context-providing instrument, include geological interpretation, dust and water vapour measurements, panoramic images and remote observations of inaccessible targets. Based on the PanCam specifications, AUPE is comprised of two wide-angle cameras and one high resolution camera, having similar fields of view to those on PanCam. It has been developed to enable deployment and testing of a representative camera rig in multiple environments thus enabling PanCam data collection, processing, and scientific operations rehearsal. AUPE has been deployed at a number of field test sites including Svalbard as part of the AMASE expedition [2], El Teide in Tenerife as part of the ProVisScout [3] and ProVisG [4] projects, the CNES SEROM in Toulouse as part of the ESTEC/CNES remote experiment [5], and various sites within the UK.

3. AUPE-1 HARDWARE
AUPE-1 uses mainly commercial off-the-shelf components (Fig. 1). The three cameras are mounted on an optical bench constructed from standard laboratory optical rail, which allows easy adjustment of camera position and the addition of further instruments. The optical bench is in turn fixed to a precision PTU (Pan-Tilt Unit). Custom filter wheels are fitted to each WAC (Wide-Angle Camera). In addition to the components pictured, AUPE-1 includes a control box holding drive electronics, power supply and a control computer.

3.1. Wide Angled Cameras (WACs)
The two AUPE-1 WACs are IEEE1394 (FireWire) monochrome cameras manufactured by The Imaging Source Ltd. The cameras have 1024 × 768 pixel resolution and panchromatic sensors without built-in infra-red filters. Their spectral response extends into the near infra-red (up to approx. 1000nm) which makes them ideal for use with filter wheels. The lenses used with the AUPE-1 WACs have an 8mm focal length, which gives an overall horizontal field of view of approximately 35°. This is comparable to the ExoMars WAC specification of 34°. The lenses also have lockable focus and iris rings. Tab. 1 gives details of the camera and lens specifications.

3.2. High Resolution Camera (HRC)
The AUPE-1 High Resolution Camera is an IEEE1394 (FireWire) colour zoom camera manufactured by The Imaging Source Ltd. This camera has a variable lens system with an effective focal length ranging from about 5 mm to 45 mm in 18 discrete steps. Zoom level, focus and iris are controllable by software. Colour imaging is achieved by means of a Bayer filter mask.
integral to the sensor. An infra-red cut filter is also present. Detailed specifications are given in Tab. 1.

<table>
<thead>
<tr>
<th></th>
<th>HRC</th>
<th>WAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>DMK 31BF03</td>
</tr>
<tr>
<td>Image type</td>
<td>UYVV, Y800</td>
<td>Y800</td>
</tr>
<tr>
<td>Sensor</td>
<td>Sony ICX204AK</td>
<td>Sony ICX204AL</td>
</tr>
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<td>1024 × 768</td>
<td>1024 × 768</td>
</tr>
<tr>
<td>Pixel size</td>
<td>4.65 μm</td>
<td>4.65 μm</td>
</tr>
<tr>
<td>Sensor size</td>
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<td>4.76 × 3.57 mm</td>
</tr>
<tr>
<td>Lens</td>
<td>Vario</td>
<td>Computar M0814-MP</td>
</tr>
<tr>
<td>Focal length</td>
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<td>8 mm</td>
</tr>
<tr>
<td>Field of view</td>
<td>6.04° - 48°</td>
<td>35° × 25°</td>
</tr>
<tr>
<td>Shutter</td>
<td>1/10000 - 30 s</td>
<td>1/10000 - 30 s</td>
</tr>
<tr>
<td>Iris</td>
<td>f/1.6 - 3.7</td>
<td>f/1.4</td>
</tr>
</tbody>
</table>

Table 1. AUPE-1 HRC and WAC specifications

The PanCam HRC is specified to have a STAR 1000 sensor (1024 × 1024 pixels @ 15μm pitch) and a focal length of 180mm, which gives a FoV (field of view) of 4.8°. The nearest usable zoom setting for the AUPE-1 HRC is zoom level 14 which gives a horizontal FoV of 6.43°. Thus AUPE-1’s HRC field of view is some 46% wider than the actual PanCam HRC.

3.3. Multi-spectral filters

The AUPE-1 WAC filter wheels have been designed and constructed in-house at Aberystwyth University from aluminium and carbon fibre sheeting for strength and lightness. Each filter wheel holds 9 × 25mm diameter filters. Three filters on each wheel are intended for colour imaging and are dichroic broadband (~100nm) filters. The remaining twelve filters - 6 on each wheel - are narrowband interference filters sampling the spectral range from 440nm to 1000nm, with a pass-band of about 10nm each. Centre wavelengths for the multispectral narrowband filters were selected using a novel filter selection method based on hydrated mineral spectral features [10]. Specifications of the filters are given in Tab. 2. The PanCam WAC’s will have 12 filters per filter wheel as opposed to the 9 filters per filter wheel used by AUPE-1.

While the broadband red, green and blue filters allow regular colour images to be taken, the narrowband filters allow extraction of reflectance spectra from images, which can be used for terrain composition analysis or advanced scene segmentation. In addition, by using all of the visible-spectrum narrowband filters, a true-colour image can be generated which accurately represents the scene as it would be seen by human eyes. Chromatic adaptation (changing apparent lighting conditions) is also possible.

3.4. Computer control

The hardware interface electronics and control computer (a standard laptop) are housed in a rugged metal-panelled suitcase that also contains a wireless hub and power regulators (Fig. 2). The whole system apart from the control laptop is powered from a single 12V DC unregulated input.

<table>
<thead>
<tr>
<th>Filter</th>
<th>Centre nm</th>
<th>Width nm</th>
<th>Camera sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>460 - 580</td>
<td>-0.51</td>
<td>-0.55</td>
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<tr>
<td>Green</td>
<td>520 - 600</td>
<td>-0.24</td>
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<td>Red</td>
<td>660 - 760</td>
<td>-0.02</td>
<td>-0.02</td>
</tr>
<tr>
<td>1</td>
<td>760 - 890</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>2</td>
<td>890 - 1100</td>
<td>0.08</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Table 2. AUPE-1 WAC (F2) filter wheel specifications

4. AUPE-1 SOFTWARE

The software system currently used with AUPE-1 has been designed to allow easy and efficient access to the PanCam emulator systems and functions while hiding the low-level details of the hardware drivers. An overview is shown in Fig. 2. The system is based around a client-server architecture using a custom binary protocol (Rover Agent Protocol) over TCP/IP.

4.1. Client-server architecture

A server process running on the AUPE-1 control computer directly controls all relevant aspects of the various hardware subsystems. Client applications access the PanCam functions by calling high-level routines (such as set_pan_tilt or get_image) within a provided client library application programming interface (API). The client library makes a connection to the AUPE-1 server host, sends the function request and parameters and returns any reply to the calling program. The client application need know nothing about the hardware or the underlying protocol.

Currently, client API bindings exist for C, Python and Java. Clients may run on any machine on the external network which can make a TCP/IP connection to the server process, and multiple clients may connect at the same time. The standard mode of operation is for the client software such as ACE (Sec. 4.3) to be run on the user's own laptop or PC, with a wired or wireless network connection to the AUPE server. However, it is also possible to run client software directly on the server laptop if required.

4.2. Auto exposure

The AUPE-1 cameras provide a basic built-in auto-exposure function, which is mainly intended for use with continuous video rather than the on-demand single images that AUPE-1 provides. To supplement this, a configurable auto-exposure function is provided by the AUPE-1 server. The auto-exposure function supports
two different exposure strategies (target mean value and histogram range fit) and allows precise control over the imaging parameters. Auto-exposure can be based on the calibration target, to avoid over-exposure and subsequent problems with whole image, or on a defined region of interest. The latter is especially useful when taking images of a colour correction or extraction of reflectance spectra.

4.3. ACE

ACE (Aberystwyth Camera Emulator) is the name given to the AUPE client software which is used to capture single images, panoramas, stereo image pairs and calibration sequences. It has been designed to be used by people who have little knowledge of the hardware, but require complex sequences of images to be captured. It allows a near real time view of the images being captured and querying and setting all of the important camera parameters. ACE is written in Java for platform independence.

5. AUPE-1 ADVANCED FEATURES

AUPE-1 has been built hand in hand with a number of advanced processing features, specifically designed for deployment as part of the ExoMars PanCam instrument. Two key examples of this are APIC[6] and RCIPP[7].

5.1. APIC

APIC (Automatic Pointing and Image Capture) is a lightweight post-processing system to automatically detect possible target rocks in a wide-angle camera image and calculate pan-tilt angles to image those targets using a narrow-angle instrument [6] (see Fig. 3). APIC has been designed to run on-board a rover system and return potentially useful close-up images as part of the first science data transmission from a new location.

5.2. Colour image and radiometric products

**Basic colour image generation:** This is performed as a post-processing step by combining red, green and blue broadband filtered images. To compensate for the different exposure times and sensor responses of the separate images, a white-balance correction is applied based on the analysis of previously-recorded images of a colour calibration target. This technique provides a useful colour image relatively quickly, but the colour accuracy is not generally as good as that obtained by using the narrowband filters to construct a colour image.

**RCIPP:** (Radiometric and Colourimetric Image Processing Pipeline). This enables radiometric correction (using “darks” & “flats”), true colour image generation, and reflectance spectra extraction from AUPE-1 multi-spectral image sets. So that science target spectra can be generated (e.g. for identifying terrain composition), then the WAC images must be radiometrically corrected [7]. A key element within this process involves measuring the reflectance of the individual grey and coloured calibration targets within a
captured image, and comparing these values with laboratory measured data. This information allows each pixel in each filtered image to be radiometrically corrected to a certified (NIST) laboratory reflectance target. RCIPP performs this correction, and the corrected filtered images for those wavelengths within the human visible light region can be used to create true-colour image products of the terrain surface (Fig. 4).

5.3. 3D image products

The possibilities for AUPE 3D image products are manifold, as is the case for PanCam 3D vision processing (Fig. 6). Digital elevation models (DEMs), panoramas, distance maps, 3D textured point clouds and derived products such as slope- roughness- and hazard maps, form the base of scientific 3D context description and give immediate feedback to scientists via derived real-time rendering applications during the foreseen ExoMars mission environment.

6. AUPE-1 FIELD DEPLOYMENTS

Field deployments have been the driving force behind much of AUPE-1’s development. Understanding the type of field locations that AUPE-1 has visited has helped to clarify the basis for some of the problems faced during the AUPE-1 development. In this section the most noteworthy of these are described.

6.1. PRoViScout

A tripod-mounted version of AUPE-1 was used to gather preliminary data from proposed rover deployment sites for the PRoViScout project [3]. PRoViScout is an EU FP7 project to demonstrate technologies for vision-based autonomous science target identification & selection, together with terrain hazard analysis and navigation for a long range scouting/exploration mission on a terrestrial planet. AUPE-2 will be the primary vision sensor (see Sec. 8).

6.2. AMASE

Arctic Mars Analogue Svalbard Expedition (AMASE) is the name given to a series of expeditions that are NASA ASTEP and ESA PRODEX funded. The goals of AMASE encompass the following [2].

- Testing portable instruments for their robustness as field instruments for life detection.
- Assessing Mars analogue environments for mineralogy and biosignatures.
- Refining protocols for contamination reduction.
- Defining a minimal instrument suite for Astrobiology science on Mars.
- Rehearsing the sample acquisition, collection and caching of suitable samples by rover platforms containing sample acquisition hardware:
  - Testing ESA instrumentation for the ExoMars mission and NASA instruments for Mars Science
Laboratory.

During past years several geologic sites on Svalbard have been investigated, using methodologies and techniques being developed or considered for future Mars missions, such as the Mars Science Laboratory (MSL). AUPE-1 has now been part of four AMASE Expeditions, acting as an emulator for the ExoMars PanCam instrument. AMASE deployments are technically very challenging for the equipment as hostile weather conditions, and long and difficult journeys into the field, put the robustness of AUPE-1 to the test.

6.3. PRoVisG

AUPE-1 was deployed on-board the EADS Astrium’s Bridget rover [9] (see Fig. 5) during the PRoVisG [4] field trail in Tenerife. The broad aims of PRoVisG were to:

- Build a framework for planetary robotic vision ground processing.
- Develop the technology to better process and visualise the existing and future data from planetary robotic missions in order to maximize the value-added exploitation of these data for research, technology and education.
- Increase public awareness of planetary robotic missions and the European contribution to their scientific evaluation.

AUPE-1 was primarily used to gather contextual images during this project, it was also heavily utilised in several field trial campaigns to gather images for stereo reconstruction and visual odometry.

6.4. ESTEC-CNES Remote experiment

This experiment was conducted on the 23rd November 2011 [5]. Its objective was to increase operational knowledge about ExoMars mission operations. During this experiment AUPE-1 was mounted on-board the CNES rover along with a number of breadboard ExoMars instruments. The rover was deployed in SEROM (CNES Mars yard) and controlled from ESTEC by a number of scientists and engineers. Various multi-spectral and 3D vision image products were produced during the experiment in near real-time.

7. LESSONS LEARNED AND THE MOVE TO AUPE-2

During the many field deployments of AUPE-1, a number of lessons have been learned, which have in turn led to significant design changes in a new system called AUPE-2. The most significant examples are presented in this section.

7.1. Mechanical configurability

The use of optical rail for the AUPE-1 optical bench allows the positions of the cameras to be varied, and also enables other instruments to be attached. However, the camera mountings are such that the cameras can only face directly forwards, perpendicular to the long axis of the optical bench. It later became a requirement to apply a degree of “toe-in” to the AUPE-1 WACs, in order to provide better stereo overlap at medium distances. A toe-in adjustment was built in to the design of the camera mounts for AUPE-2.

The nominal camera positions on the AUPE-1 optical bench were only indicated by alignment marks, which had to be matched by eye when mounting the cameras. It was not always possible to keep the cameras mounted during transport, hence this was one source of small variations in the geometry of the camera system as a whole. This problem has been partially addressed with AUPE-2 by using the ends of the optical bench as mechanical alignment points for the AUPE-2 WACs. Meanwhile, automatic calibration measures have been developed within PRoVisG & PanCam 3D Vision to mitigate the problem.

7.2. Field deployment

Two primary concerns relating to AUPE-1 were its robustness and portability. It was also desirable for it to be as simple to use and easy to deploy. These factors have led much of the recent development on AUPE-2 particularly in relation to the optical bench, control computer and power.

Optical bench: The AUPE-1 optical bench was comprised of three separate lengths of optical rail (see Fig.1). The intention of using three lengths was to increase rigidity without compromising weight. However on occasions the optical bench had been observed to flex. Also after repeated thermal cycling the clamps holding the rails together became less effective, allowing slippage. This problem has been resolved with AUPE-2 by the introduction of a 30 x 30 x 500 mm hollow box rail. This is highly rigid and is comprised of a single piece of aluminium.

Control hardware: The control hardware must be sufficiently robust to enable field deployment in a wide variety of field sites and environmental conditions, ranging from the high Arctic in Svalbard to atop Mount Teide in the subtropical region. This in itself produced a number of technical challenges such as moisture & dust resistance, thermal & solar radiation resilience, impact protection and portability. The AUPE-1 control system proved to be very effective over the 2 years that it was in service. The aluminium suitcase that housed the control computer provided ample impact protection and some limited protection from moisture. It was however never designed as a permanent solution, so when AUPE-2 was proposed efforts were made to build on the strengths of the previous system, primarily focusing on improving its robustness and also drastically reducing its size. Portability was always an issue with
the AUPE-1 system: it required numerous cables to be carried separately and also needed some re-assembly at each deployment location. External power was also required for part of the system as only the control laptop had its own batteries.

Power: AUPE-1 required a 12v power supply and a charged laptop battery (this could be charged in the field through the use of a 12v inverter). This was generally not a problem when AUPE-1 was deployed on a rover, as the laptop battery would last some 2-3 hours and then could be replaced with a spare and most rover platforms have the capability to provide a 12v power supply. It was however more troublesome when using AUPE-1 as a tripod system, as this generally resulted in a 12v car battery being carried into the field. AUPE-2 would eliminate this problem by having internal batteries. If these batteries become exhausted, the entire system can be operated off a single 12v supply.

7.3. Auto exposure

In order to fully utilise the dynamic range of the camera sensor and capture as much information as possible, it is important to select a correct exposure setting. Initially a very basic auto exposure algorithm was employed, sampling only the white square in the calibration target. This caused some difficulty during field deployment as it was not always possible to place the calibration target in every image - mainly due to time constraints - and changing light conditions made it very difficult to use previously calculated auto exposure values. Because of these problems the camera's internal auto exposure algorithm was replaced with our own implementation. This algorithm alters the exposure setting until the measured mean pixel value of the image falls within an acceptable tolerance range of the requested target value. Initially this method was found to be very effective, both consistently producing aesthetically pleasing images and enabling basic scientific assessment by maintaining maximum information content as a balance between minimum saturated areas and maximum contrast in low illumination portions of images.

As the scientific assessment of the images intensified problems with this approach were highlighted. Mainly, these were caused by overexposed pixels within either the target region, or in the colour regions of the calibration images, especially in scenes with high dynamic range. In response to this another auto exposure algorithm - histogram fit - was implemented. At each step of the algorithm, a histogram of the current image is computed. Optionally, a proportion of the highest-valued pixels ("outliers") is discarded, then the exposure time is adjusted to fit the remainder of the histogram within a specified target range of pixel values. Using this algorithm it is possible to place a limit on the number of pixels that are allowed to be overexposed within the target region. This algorithm is particularly useful when applied to a chosen sub-region of the image, such as the area containing a calibration target.

7.4. Camera and filter specifications

AUPE-1 utilised two off-the-shelf computer vision cameras. These cameras both utilised the IEEE 1394 interface. This in itself eventually caused some significant deployment issues, as this interface is no longer commonly supported by lightweight portable platforms. In addition, the cameras were inherently designed for streaming video applications. When AUPE-2 was specified changing the interface was a priority, and the GigE interface was selected. The lenses used by AUPE-1 also required some attention as the focus point shifted in the near infra-red range of the spectrum. As an autofocus mechanism was not practical, lenses that did not suffer from this focus shift were sourced for AUPE-2, thus eliminating the problem.

8. AUPE-2

AUPE-2 is now the successor to AUPE-1 and features a number of improvements over its predecessor, based on experience with AUPE-1 in the laboratory and in the field. The basic camera interface technology has changed from IEEE1394 FireWire to GigE Vision (which uses ethernet). The cameras have higher resolution and more sensitive imaging sensors: up to 2452 × 2056 for the AUPE-2 WACs and 1388 × 1038 for the AUPE-2 HRC. Binning and windowing options allow for a more accurate emulation of the ExoMars PanCam, with 1024 × 1024 resolution images and up to 12-bit data. The lens system has been upgraded to allow improved near infra-red performance.

In addition, a smaller and more rugged control system has been designed using an embedded PC. An integrated touchscreen will allow control of and monitoring of AUPE-2 and basic data capture without requiring a separate laptop. Improvements to image capture functions have been made possible by the new hardware, including support for rapid, synchronised stereo image capture for digital elevation map generation and visual odometry. In addition, within PRoViScout a CORBA interface has been implemented to make the system compatible with generic robotics applications.

8.1. AUPE-2 Wide Angled Cameras (WACs)

The AUPE-2 WACs are Manta G-504B GigE Vision cameras made by Allied Vision Technologies. They have 5 megapixel monochrome sensors and use a gigabit ethernet connection for control and data. See Tab. 3 for specifications.

The high resolution and binning/windowing options make it possible to more closely emulate other sensors (such as the STAR-1000) using these cameras. The
lenses have been chosen to operate correctly across the visible range and into the near infrared, at wavelengths up to 1000 µm and represent a significant improvement over the lenses used with AUPE-1.

Figure 7. AUPE-2

8.2. AUPE-2 High Resolution Camera (HRC)

The AUPE-2 High Resolution Camera is a Manta G-146B GigE Vision camera made by Allied Vision Technology. It has a 1.3 megapixel monochrome sensor. See Tab. 3 for specifications.

<table>
<thead>
<tr>
<th>HRC</th>
<th>WAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Manta G-146B</td>
</tr>
<tr>
<td>Image type</td>
<td>Mono (8-12 bit)</td>
</tr>
<tr>
<td>Sensor</td>
<td>Sony ICX267AL</td>
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<tr>
<td>Resolution</td>
<td>1388 x 1038</td>
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<td>Pixel size</td>
<td>4.65 µm</td>
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<tr>
<td>Sensor size</td>
<td>6.45 x 4.83 mm</td>
</tr>
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<td>Lens</td>
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<tr>
<td>Focal length</td>
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<tr>
<td>Aperture</td>
<td>f/2</td>
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<tr>
<td>Field of view</td>
<td>Variable</td>
</tr>
<tr>
<td>Shutter</td>
<td>31 µs - 60 s</td>
</tr>
</tbody>
</table>

Table 3. AUPE-2 Camera specification

Currently, the AUPE-2 HRC has a manually variable zoom lens to allow emulation of different possible HRC lens systems. There is at present no filter wheel on this camera, so only panchromatic images can be taken.

8.3. Multi-spectral filters

The filter wheels for AUPE-2 are based on the same design as used with AUPE-1, with allowances made for the larger filter size required by the new lenses. The filter set for AUPE-2 is designed to emulate the proposed ExoMars PanCam ‘FERRIC’ filter set (see Tab. 4) [8], rather than the nominal ‘F2’ set as used by AUPE-1 (see Tab. 2).

<table>
<thead>
<tr>
<th>LWAC</th>
<th>RWAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>440, 500, 530, 570, 610, 670</td>
<td>740, 780, 840, 900, 950, 1000</td>
</tr>
</tbody>
</table>

Table 4. Filter wavelengths for ‘FERRIC’ set (nm)

8.4. Computer control system

AUPE-2 has a more compact and rugged control system (Fig. 8) when compared to AUPE-1 (Fig. 2). Use of a miniature computer (FitPC-2i) has enabled the elimination of the control laptop, with considerable saving of space, weight and total power consumption. A touch-screen display is provided for basic control and monitoring of AUPE-2, and a gigabit ethernet interface provides the main data connection to clients. Wireless is still available as a secondary connection option.

The control system is housed in a rugged metal case with a viewing window through which the display can be seen. Cabling has been greatly simplified relative to AUPE-1, with one combined cable harness and a separate ethernet cable at the control system end. At the camera payload end, just three cables need to be connected – one to the PTU mechanism and two to the optical bench. Clients connect via a second ethernet connector on the control box, or by using WiFi. As well as shortening setup time, the new control system has significantly better weather resistance than AUPE-1.

Figure 8. AUPE-2 control hardware.

8.5. AUPE-2 field deployments

The AUPE-2 system is still relatively new, and has not as yet been deployed to many locations. Its first deployment was to a field site in the black mountains, (Brecon beacons, Wales). This deployment lasted three days and was primarily focussed upon the capture of multi-spectral images (see Fig. 9). The new system performed well and is now being prepared for more ambitious deployments such as future AMASE expeditions and Tenerife 2012 (as part of the PRoViScout field trial).

9. CONCLUSIONS AND FUTURE DEVELOPMENT

AUPE-2 is still in its early stages but is showing great promise. As the system is used more and more, opportunities for improvement will become apparent.
Some issues have already been identified during early testing and deployment, such as stereo synchronisation, various modes of stereo-dependent exposure control and support for high dynamic range data.

**Hardware:** The camera toe-in facility is valuable but currently difficult to adjust with precision, so alternative methods of achieving toe-in will be investigated. To allow for additional instruments on the optical bench, a PTU with a larger payload capacity will be considered, along with a more rigid tripod system for deploying AUPE when it is not mounted on a rover. The AUPE-2 HRC currently has a monochrome sensor but no filter wheel. It is anticipated that a broadband RGB filter wheel will be developed for it in the future.

**Software:** AUPE-2 offers the opportunity to explore higher-precision data than was available from AUPE-1 (greater resolution and more bits per pixel). This facility is underused at present, but we plan to further develop our image capture software and processing pipelines to allow exploitation of high resolution, high dynamic range multi-spectral images. Future software work will also include the development of the touch-screen based interface for control and image capture.

![Figure 9. AUPE-2 in Brecon 2012](image)

**Multi-spectral filters:** The aim for AUPE-2 is to make the best emulator of the PanCam system possible with available resources. To date this has meant using “off the shelf” filters to approximate the ones that will eventually be deployed as part of the instrument. Such an approach has limitations when an accurate mineralogical analysis is desired [8]. It is anticipated that a set of representative ExoMars PanCam filters will be obtained for AUPE-2 when a firm mission selection is made and the needed resources become available.

10. **ACKNOWLEDGEMENTS**

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11. **REFERENCES**


