Achieving Global Awareness via Advanced Remote Sensing Techniques on 3U CubeSats

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ABSTRACT

The cost models for return on investment for constellations of large spacecraft providing high quality, high temporal resolution Earth observation data are not currently sustainable. Even with economies of scale, the costs involved in the materials and launch of the spacecraft alone will result in an expensive final product only accessible for customers of considerable means to afford the data. However, advances in the miniaturization of spacecraft systems for high resolution, high quality imagery from nanosatellites/CubeSats make the prospect of constellations of 50+ spacecraft in complimentary orbits an affordable and potentially highly profitable concept.

In addition, security, disaster relief and environmental monitoring users, amongst others, desperately need high temporal resolution Earth observation data with global access. Climate change impacts, resource conflict and geopolitically driven cross-border movement, all tax the abilities of remote sensing systems to acquire timely data. Nanosatellites deployed in constellations can offer global coverage from a very low cost package, particularly the CubeSat standard. Further, the availability of low cost imaging equipment (CCDs, COTS optics and deployment mechanisms) has shown that suitable cameras for delivering high resolution can be built in a very small package, compatible with the limited envelope of the CubeSat standard.

This paper will discuss the outcomes of two recent studies and the ability of current technologies to provide global awareness in two key Earth observation areas; sub-1m resolution, high resolution visible and near infrared imagery for bushfire early detection. The paper will show that these technologies are not only feasible but could be ready for on-orbit demonstration within the next 2 years. ..

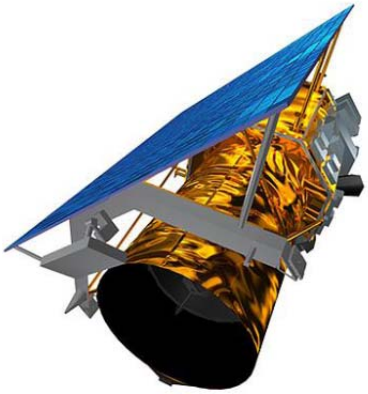

Figure 1 Artist's impression of GEOEYE, a high spatial resolution mission

INTRODUCTION

Earth Observation (EO) missions have traditionally involved large, complex spacecraft with multiple payloads. This has led to EO spacecraft having a large price tag and being limited in numbers. Whilst the EO payloads on these missions are typically highly sophisticated, outputting excellent data with high spatial resolution for mission scientists and users, there is often a data gap due to having only one spacecraft for each payload. Nanosatellites are not known for their EO capabilities and their physical limitations will always hinder their ability to provide quality high spatial resolution imagery. However, current developments are proving that it is possible to supplement the data from high spatial resolution payloads with good quality high to medium resolution data from nanosatellites of 5kg and less. Due to the low physical volume, mass and cost of these spacecraft, it then becomes practical to have constellations of these Earth observation nanosatellites, opening up the opportunity to start to significantly improve the temporal resolution of military, commercial and science data from space.

Two studies conducted recently evaluated the payload and platform requirements for two high quality optical systems on a 3U CubeSat, it was determined that the technology needed to deploy a 3U CubeSat based constellation of high resolution imaging spacecraft is not only feasible, but available today.

The first study concentrated on the use of nanosatellites, together with a low cost, thermal infrared camera, to provide an early warning system for detecting bushfires. Bushfires are damaging to valuable ecosystems and human lives, as well as having appreciable economic impact. The focus was to look at existing, readily available technologies and carry out analysis to determine if a low cost, quality imaging system can be developed to provide a thermal imager capable of fitting within the 3U CubeSat form-factor. We also evaluated whether we could achieve a sufficient spatial resolution to recognize fires at an early stage. This was found to be a highly credible approach and a preliminary payload and mission concept was developed as an output to the study. With the use of such a constellation, there could no longer be a need for human fire spotters on platforms and spotter planes, which could help further to prevent the loss of homes and lives that often accompany bushfires.

The second study focused mainly on the feasibility of a high resolution imager. More specifically, our target was an imaging capability of <10m Ground Sampling Distance (GSD) in visible and near IR color bands and targeting sub 1 hourly access to any point on the planet. There were two main unknowns that we covered: 1. Can the optics of a high resolution imager be downsized to fit a 3U CubeSat? 2. Can the platform support this high performance imager? The outcome of the study demonstrated that the payload deployable optics can fit between 1U to 2U of the platform volume, leaving an equivalent volume for the platform systems and imager electronics. In fact, it was found that our deployable mirror concept could actually achieve sub-1m GSD from a 400km orbit. We were also able to demonstrate that the spacecraft platform and the attitude determination and control system could meet the taxing demands of the imager.

There is no doubt that the ability to fly advanced EO missions using nanosatellites presents an exciting opportunity for the EO and science community in terms of temporal resolution of data. It is hoped that this miniature EO mission will stimulate the beginning of big opportunities for future EO science and Earth monitoring missions using nanosatellites.

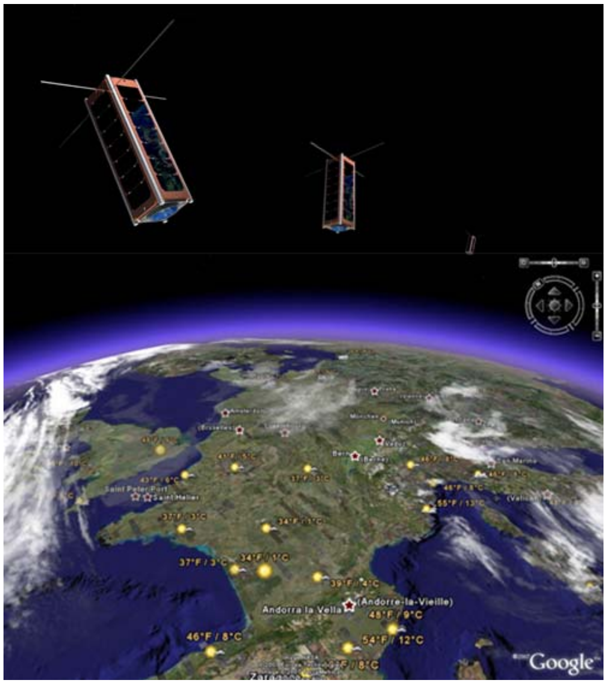

Figure 2 High utility, value high temporal resolution missions s have wide ranging applications, such as near-live maps.

WHAT IS TEMPORAL RESOLUTION

When talking about gathering data, we must consider the frequency of the data collection in addition to the data itself. For instance, a super-high spatial resolution imager (i.e. the imager has the ability to resolve a high degree of fine physical detail on the ground) may only take one image per month over each area of interest. Therefore, it would be said that this imager has excellent spatial resolution, but poor temporal resolution.

Compare this with a constellation of spacecraft with a low spatial resolution, and is only able to resolve very large objects on the ground (i.e. islands), but there are 100 such spacecraft in complimentary orbits, providing a fresh image of the subject area every 20 minutes. One would say that this imager has a poor spatial resolution, but a high temporal resolution.

The challenge for high temporal resolution missions is to provide a payload and platform with sufficient performance to make the data from a constellation of such satellites worthwhile.

EO CUBESAT APP 1: 'WILDFIRE'

More than 30% of the global land surface experiences significant wildfire activity of which the densest wildfire activity occurs between 30°S and 20°N. Although seasonal patterns in fire distribution have been observed to different degrees, wildfires have a clear diurnal cycle: Fire activity often peaks in the afternoon (1-4 pm) when weather conditions are most favorable for burning (temperatures are high and humidity is low). The temperature of wildfires varies from 500 to 1200 K, depending on the type of combustion. A single wildfire can consist of many smaller individual fire components, each with a different temperature. Forest areas with a heavy fuel load tend to burn at a higher intensity of which the fuel stays hot longer after the fire front has passed. However, areas such as grasslands and agricultural areas tend to burn faster and at a lower intensity. Due to the transient nature of wildfire, users of satellite-based active fire detection data would prefer observations to be made as frequently as possible, preferably hourly, with a concentration of observation times during the daily afternoon peak.

Figure 3 Wildfires are a serious problem for many regions of the World.

For effective firefighting and suppression activities, it is important to obtain accurate geolocation of the fire front, the intensity of the fire, where the fire has passed through, what damage it has caused and where the fire is heading (inferred from the direction of the smoke plume). A sensor for wildfire detection and monitoring should therefore ideally consist of both thermal (at a medium resolution) and limited optical sensors (at medium to high spatial resolution). Thermal sensors at 4 and 11 μm are typically used in active fire detection sensor systems. Visible bands could be limited to the near-infrared and red bands.

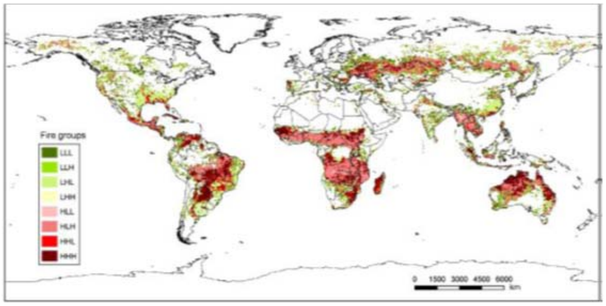

Figure 4 Wildfire global affected areas.

Currently most active fire detection and monitoring data is freely available at a frequency of approximately 4 observations per day (from MODIS). Of the current operational active fire detection sensors, MODIS has the highest resolution in the thermal bands but its 1 km spatial resolution is too coarse to be used for tactical firefighting. Higher temporal resolutions are available at several observations per hour from geostationary sensors, but these have a coarser spatial resolution (3-4 km) and are not sensitive enough to all fire activity so that they are not operationally useful.

There is a strong need for a both a higher spatial resolution in especially the thermal bands and a higher temporal resolution in observations among users and providers of active fire data. A low cost space based approach to wildfire identification and tracking to support early phase mitigation would rapidly offer savings in excess of the cost. The WildFire project aims to exploit a constellation of nanosatellites to address the need for higher temporal resolution data, which will also further enhance coverage from existing large, low temporal revisit satellites and costly range limited aircraft. This will improve international capability for early warning of fire detection and mapping and will greatly add to wildfire mitigation efforts.

To facilitate this, the WildFire project aims to design a compact multi-band imager integrated into a CubeSat platform plus retrieval algorithms; these technologies, whilst tailored for fire monitoring here, also have much broader applicability. The payload to meet the mission is defined as an uncooled dual-band Medium Wave / Long Wave InfraRed (MWIR / LWIR) detector with an optical imager and GPS. Potential off-the-shelf technologies from a range of suppliers have been surveyed to identify a baseline architecture. Based on this payload package, a platform design is proposed and two mission concepts identified as compatible with the resultant Fire Early Warning System (FEWS) nanosatellite. The first is a standalone mission for a non-homogenous constellation of around 18 nanosatellites launched in four batches of 4-5 satellites as payloads of opportunity and resilient to a range of inclinations and altitudes. The second is an extension to the ESA /DLR FireBIRD mission, to assess how the FEWS nanosatellites could be used to increase mission return for this existing concept.

Following, a more thorough development of the sensor concept, it was concluded that given the need for a single coherent fire monitoring network, it would be preferable that a route of cooperation with the FireBIRD mission be pursued. Due to cost limitations, there are only a small number of funded satellites due to launch based on 2-channel IR (infrared) detectors and these focus on increased spatial, rather than temporal, resolution. Utilizing CubeSats to provide a slightly lower spatial resolution in return for higher temporal resolution will increase the value of the full dataset, addressing the need for rapid response, and provide a clear route to market.

It has not been possible to fully confirm the feasibility of the mission within the scope of this study; two areas are identified as priority for further study:

- IR payload development towards a sensor prototype suite and test bench to confirm benchmark performance with respect to thermal observations and investigate miniaturization of a scanning mirror
- Demonstration of a clear route to market for the mission data products and market value of the data, if possible through collaboration with the FireBIRD team. A revenue stream of at least 1.4 MGBP.yr-1 over 10 years is recommended.

EO APP 2: 'CUBESAT HIRES IMAGER'

A fundamental problem in designing Earth Observation (EO) instruments for small satellites is that of ground resolution. Whilst the problems of weight, power, heat management etc. are not trivial, they are not fundamentally limited by the size of the satellite, whereas the spatial resolution of an optical system is set by its aperture:

$$Resolution\ (radians) = 1.22 \times \frac{\lambda}{Aperture\ Diamter}.$$

For a 10cm aperture in a 350km orbit this equates to a visible image of 2.1m resolution on the ground. Numerous users of EO data require ground resolutions better than 1m, especially in circumstances where man's effect on the planet needs to be determined: buildings, roads, vehicle activity and the like (see Figure 5).

The UKATC, alongside Clyde Space as part of the Gioconda consortium, is developing a high spatial resolution imaging system for small satellites based on deployable mirrors. This project builds on active and adaptive optics technologies developed at the UKATC for large, ground based telescopes such as the 4m VISTA Telescope. By deploying a number of mirror segments from the body of a CubeSat (see Figure 6) an effective aperture of 30cm can be provided. In practice there are a number of specific problems that need to be addressed: fabricating optical surfaces, deployment and alignment mechanisms within the size and weight constraints of the CubeSat; sensing and correcting the alignment of the surfaces and providing pointing stability that takes advantage of the resolution.

Figure 5 Comparison of the resolution of man-made structures using simulated blurring of a real EO image

2.1m resolution (10cm aperture at 500nm wavelength and 350km altitude)

0.7m resolution (30cm aperture at 500nm wavelength and 350km altitude)

Given the size, it would be possible to fabricate the mirror segments by grinding thin glass substrates, but protecting such materials during launch and deployment is difficult. The UKATC has been working on lightweight reflector technologies for LIDAR systems using diamond turned metal mirrors. Diamond turning produces scratch and dig defects that affect the optical performance in the visible, but preprocessing (turning cooled substrates) and post processing techniques (post polishing, ablation) can be used to provide optically clean surfaces suitable for visible wavelengths.

Deployment mechanisms for CubeSats have generally relied on torsion actuation and mechanical end stops. The tolerances, when multiplied by the arm length, mean that the alignment mechanism requires significant throw (several mm) at a resolution of 0.1 microns. The alternative is to use a driven deployment mechanism; this can then also be used as a coarse adjustment for the alignment. Investigations are underway comparing several alternative drive mechanisms (gear motors, piezo motors, linear drives etc.). Some of these alternatives will be instantiated as part of a bench-top demonstrator to allow us to compare the two deployment systems, the drives systems themselves and the alignment algorithms.

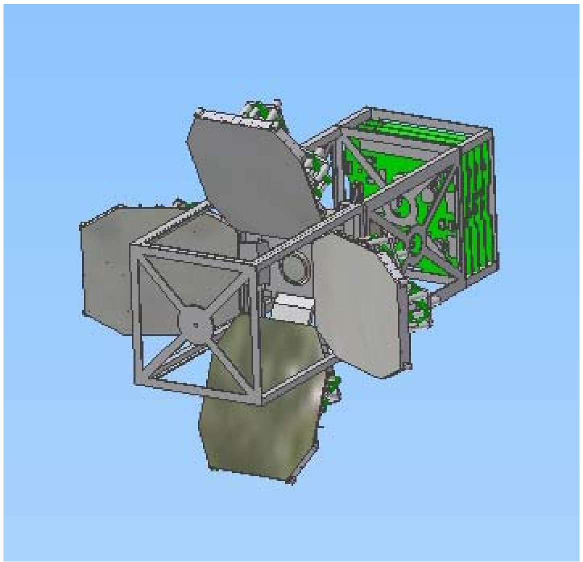

Figure 6 Segmented mirror deployment for a 2.5U Cubesat frame.

Sensing and directing the correction of the mirror surface figure is an area which the UKATC has developed for a number of large, ground based telescopes. The principle difference in the CubeSat (apart from the size) is the references; physical reference to the structure cannot be relied upon considering the thermal cycle the satellite is likely to endure, and the sensed image contains no convenient point sources. One brute force approach would be to turn the CubeSat and focus on a star. However, developments in wide field telescopes such as VISTA have necessitated the development of phase reconstruction techniques that work with extended fields, and variants of these algorithms (based on diversity measures) can be used to align the segments using ground images. These techniques are not computationally trivial, but it is possible within the size and power constraints of a small satellite system by taking advantage of simplification of the algorithm and hardware implementation.

The final problem we are addressing is that of pointing and stability. Again, alternatives are being examined: providing extra maneuverability and using a pitch-and-roll technique to minimize ground motion during an exposure (Forward Motion Compensation). Another alternative is to use Time Delay Imaging (TDI) on the imaging CCD to provide a rolling exposure as the satellite passes over the ground. Both of these require accurate timing and knowledge of the orbital components. These, together with the miniature reaction wheels and TDI readout circuitry, are being developed by us and other participants in the Gioconda consortium.

Several market areas (e.g. security, disaster monitoring, pollution monitoring) are keen to benefit from the advantages of small satellites, such as cost, time to launch and constellations. By providing high resolution imaging capability for these platforms in the visible and near IR we expect that many new customers will commit to using small satellites.

PERFORMANCE REQUIREMENTS ON THE CUBESAT

For both applications there is a significant demand on the performance of the CubeSat platform itself in order to host payloads of this type. Power and Communications are perennial issues for very small spacecraft, but these are related to the ability to get the data from the spacecraft to the ground. For the most part, these problems are solvable with deployed/additional solar arrays, bigger batteries, more efficiency and a more capable communications system. In addition, on-board processing of payload data, including compression algorithms and data management also push the limits of the more typical on-board computer solutions currently used on CubeSats. Last, but by no means least, the attitude determination and control system on-board is a significant challenge.

For the purposes of evaluating the requirements on the platform, we have taken the EO APP2 CUBESAT HIRES IMAGER as the example case. In this case, the CubeSat platform systems required to support a high resolution imaging mission that would provide a <3m GSD resolution image from an altitude of 600km. The field of view of the telescope is approximately 1.8 km for a 26 mm detector array. This system requires the use of a time delay integration (TDI) line scan sensor. The reason for this is due to the signal to noise ratio (SNR) which shows that the image needs to be integrated over approximately 70 TDI pixels to obtain a SNR > 100.

The high performance nature of the payload places very strict demands on the platform performance. These include:

- Attitude Determination and Control System (ADCS)
- Positioning Knowledge
- Pointing Knowledge

- Power for payload operations and data downlink
- Transmit high data rate
- Data storage, processing and compression capability

ADCS

In order to determine the requirements for the ADCS we have examined the ADCS requirements for another UK high resolution, small satellite imaging mission; TOPSAT [6]. TOPSAT is a 120kg small satellite capable of capturing images with a ground resolution of 2.5m from a 600km orbit. The swath of the image is 15km and a typical image size is 15km x 15km. In order to achieve the required SNR in varying illumination conditions, TOPSAT was also required to perform Time Delay Integration (TDI) maneuvers, making the comparison between this feasibility study and the TOPSAT mission very relevant.

TOPSAT also had a requirement to 'off-point by up to +/- 30° in the roll axis in order to increase the imaging capability of the mission (i.e. take pictures of areas not directly underneath the spacecraft). Given that the imaging area available to the CubeSat imaging system is almost a factor of 10 less than for TOPSAT (1.8km compared to 15km), the ability to off-point successfully will be all the more important in order for this imaging concept to be successful.

The ADCS requirement can be split into two main imaging control modes:

1. Cruise Mode: the spacecraft maintains a specific control mode, e.g. nadir pointing, pitch spin, magnetic align, sun tracking. In this case, the mission is likely to maintain nadir pointing throughout the orbit, ensuring that the sensor of the imager is not in danger of being exposed to full sunlight which could be damaging, and also ensuring that the spacecraft is already prepared for imaging when required.

   In this mode, the spacecraft must be able to determine the location of the target to within 1km minimum (i.e. the target no closer than 0.4km from the edge of the field of view ensuring that a target of 0.4km x 0.4km can be captured.

   Therefore, the pointing accuracy of the spacecraft needs to be <0.1°. This is the same as for the TOPSAT mission. The spacecraft positioning knowledge must be better than 100m to ensure accurate image target capture.

   This control mode should be possible to achieve using conventional, but miniaturised sensors and actuators. The TOPSAT mission achieves a similar control attitude using a combination of fine sun-sensors, Earth Horizon sensor and 3-axis reaction wheels. There would also be a need for magnetometers to maintain a degree of nadir pointing during eclipse. Also, magnetorquers will provide a means to de-saturate the reaction wheels.

   The off-pointing requirement of 30° will be part of this control mode.

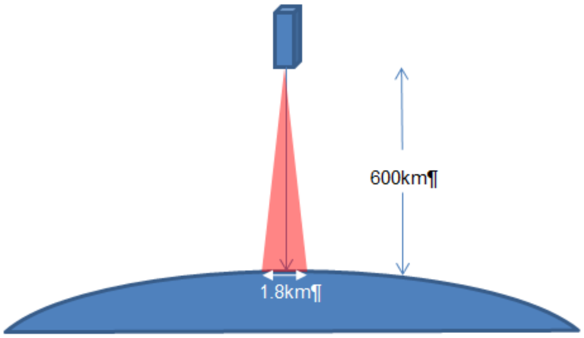

Figure 7 Swath-width at an altitude of 600km

2. Imaging Mode: The spacecraft will be required to slew in the pitch axis by about +/- 20° in order to facilitate TDI. During imaging, the stability of the platform is essentially more important than the pointing accuracy. In fact, disturbances from the attitude control system are large enough to reduce the platform stability to a level unacceptable for good quality imaging. Therefore, it is necessary for the spacecraft to suspend the attitude control and allow the spacecraft to pitch at a rate already established in the lead up to the image capture.

This is the simplest approach from a hardware perspective and, given the constraints of a CubeSat platform for power, volume and mass, this puts the majority of the complexity onto the control algorithms and processing. The ADCS system must establish a pitch of the spacecraft of about 10° and establish a maximum pitch rate change of about 0.6°/s to achieve 70 TDI pixels when obtaining images of 1.8km x 1.8km. The time for the capture of this image would be 30s. For larger images (i.e. greater than 1.8km depth, same 1.8km swath) a slower rate would be required. The attitude stability for the imaging phase at this resolution would need to be better than 12.4 arcsec/s.

Pointing Knowledge, Pointing Control and Position Knowledge

Clyde Space is currently developing an Active Attitude Control system consisting of a set of 6 embedded magnetorquer drivers (compatible with Clyde Space embedded solar panel magnetorquers), a MEMs Inertial Measurement Unit consisting of gyros, accelerometers and magnetometers, targeting a 2-axis pointing capability of +/- 5° and sensing to 1° for the UKube-1 mission. The module also interfaces to a Global Navigation System daughter board fed from a GPS Patch Antenna mounted on a Solar Array.

ADCS Architecture

The Clyde Space ADCS system is FPGA based. The central Actel ProAsic3 FPGA interfaces to the sensors and actuators. A secondary processor (PIC) provides a watchdog function and can place the spacecraft attitude into a safe mode and also de-tumble the spacecraft should the need arise. The FPGA used in the design has a high gate count and has the ability to be modified for more advanced systems. The design uses a Matlab VHDL generator meaning that control algorithms can be programmed from Matlab direct to the FPGA.

The basic ADCS system has 6 MTQ drivers, 6 Sun-sensor inputs, 3 axis magnetometer, 3 axis rate sensor and can also use the solar array currents to augment the sensor system. A GPS daughter board can be added as an option.

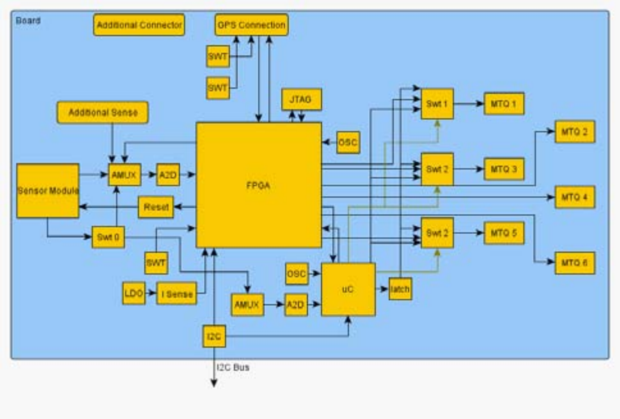

Figure 8 ADCS Architecture

For the high resolution imager mission, the system would have 3 axis reaction wheels. For this mission the system may need to be modified to configure the wheels in a zero momentum bias configuration to minimize disturbances during imaging. The motors used in the design are limited to a maximum torque of up to 5mNm and a maximum speed of 6500RPM. The rotor and flywheel have a combined inertia of 4500^{-} gmm^{2}. The total mass (estimated) of the system is <200g (3 wheels + electronics). The reaction wheels + electronics fit within a volume of 75mm x 45mm x 30mm.

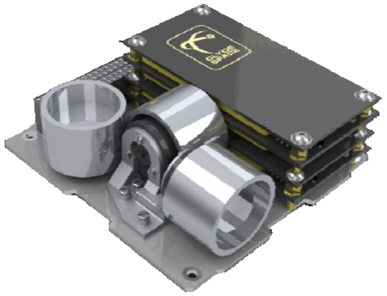

Figure 9 3D model of 3-Axis reaction wheel system incorporating a 20Whr battery.

A required pointing knowledge of better than 0.05° is required to achieve the desired attitude control. For this an Earth horizon sensor or star tracker will be required. There are now a number of commercial star trackers available that will provide this level of accuracy.

In addition, Clyde Space is in the process of developing a miniature analog sun-sensor with an expected performance better than 0.1° knowledge; size 16mm x 8mm x 3mm; mass less than 5g; power consumption of a few mW (including interface circuit). This technology has the potential to increase the pointing performance of the system without the need for more complex sensors.

Power

Due to the spacecraft configuration with the deployable mirrors, it is necessary for the spacecraft to have deployed solar panels

Figure 10 HiRes CubeSat with solar panels in deployed and stowed configuration.

Clyde Space has developed Electrical Power System solutions capable of managing over 70W of instantaneous power from body mounted and deployed solar panels and safely delivering this power to the bus and payload systems. The figure below shows an XU-EPS2 ('XU' refers to the ability to configured this with more than 3U CubeSats with deployed panels – the system is also used on 6U and 12U CubeSats).

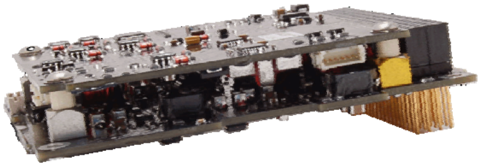

Figure 11 The highly successful, high efficiency power system for CubeSats from Clyde Space. Can interface to over 70W of instantaneous solar power.

The EPS uses multiple solar panel interfaces to provide the ability to track the maximum power point of the various solar panel faces with differing illumination angles and temperatures, maximizing power to the spacecraft bus.

The EPS also provides regulated 5V, 3.3V and 12V as standard at efficiencies of over 90% and up to 98% on the 5V and 3.3V lines. More recently, firmware developments have introduced safety features such as the 'dead-man's switch', which will automatically reset the spacecraft power buses in the event that no command is received by the power system for 30 minutes.

The EPS is combined with a Power Distribution Module, which is effectively a bank of 24 commandable over-current protection switches with dedicated current telemetry monitors. This enables payloads and systems to be duty-cycled ON and OFF as and when the mission demands. This is essential for managing power budgets and maximizing mission performance.

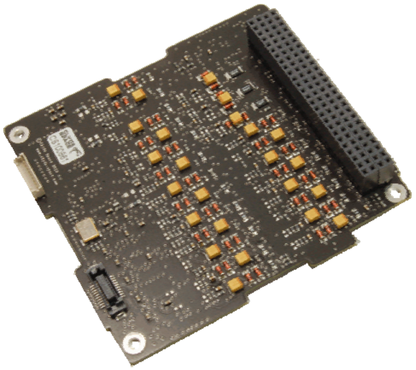

Figure 12 CubeSat Power Distribution Module

We have developed our CubeSat battery product to be as configurable and adaptable to different mission requirements. The flat-packed nature of our cells makes them very mass and volume efficient, enabling us to offer excellent energy densities. Our battery cells use very well established processes and are produced by the excellent battery manufacturer, VARTA, in Europe. Despite being an older, more established technology, the energy densities achieved are still higher than any other CubeSat battery. At a cell level, the energy density is 215Wh/kg and at a battery level over 150Wh/kg. In addition, our battery now has significant flight heritage are used on more CubeSat missions than any other.

All batteries have an integrated, thermostatically controlled battery heater and built in over-current protection. The stand-alone battery and Remote Battery Board each have dedicated I2C nodes for telemetry and command.

Figure 13 High energy density, CubeSat batteries with significant flight heritage. 30Whr battery (left), 10Whr Remote Battery Board (right).

Solar Panels

We typically use the Spectrolab UTJ cells for our satellite solar panels, and we as much as possible for the large area cells as these are the most cost effective for the missions we supply to. The UTJ solar cells have dimensions of 39.70mm x 69.11mm. They are GaInP2/GaAs/Ge multi-junction cells, have an efficiency of about 29%.

Figure 14 3U Solar Panel for NASA Firefly mission.

The development of deployable solar panels has enabled higher power payloads to be considered for use on CubeSats. Single and double deployed panels can increase the solar cell surface area dramatically and also provide the option to have additional sensors and antennae integrated into the deployables.

Figure 15 Deployable panels can significantly increase solar cell surface area.

Mission Interface Computer (SA-MIC) [Clyde Space and Steepest Ascent]

The Steepest Ascent Mission Interface Computer (SA-MIC) provides next generation on-board computing capability for advanced CubeSats. With more sophisticated platform units becoming common place, a highly-reliable, low-power, low-cost, yet capable on-board computing capability is essential. The SA-MIC meets these demands, supporting Telemetry and Telecommand operations, as well as providing a platform to perform advanced on-board pre-processing of data, allowing for more sophisticated analysis to be performed and more efficient use of available downlink bandwidths. The SA-MIC has a powerful Cortex-M1 Primary Processor and 350 MHz flexible processing fabric. Other key features of the SA-MIC include its mass storage capability, allowing data to be stored centrally on up to 16GB of mass memory. The SA-MIC also would be able to provide a platform for image compression to reduce the time to download data.

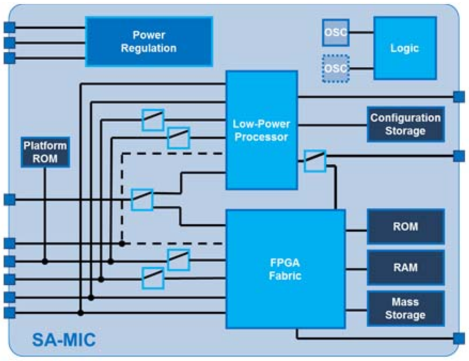

Figure 16 MIC Block Diagram

When configured as a Data Processing and Storage Subsystem SA-MIC provides a number of options that allow different system architectures to be accommodated. The FPGA Fabric can be used to implement data processing algorithms, allowing data to be pre-processed before being transmitted to the ground. The attached ROM, RAM and Mass Storage can be used to accommodate more complex algorithms that require buffering of data as well as filter weights/ lookup table values to be stored.

Figure 17 Mission Interface Computer

Data downlink

As part of the UKube-1 mission, Clyde Space is demonstrating the ability to provide low-cost high data rate transmission by flying a 2Mbps S-Band TX and patch antenna as a payload. The STX (S-Band TX) has been developed by Cape Peninsula University of Technology (CPUT). The STX has various modes of operation:

- In configuration mode the carrier frequency, power level, data rate and modulation scheme can be selected.
- In synchronisation mode synchronisation bytes are sent in order for the ground station receiver to achieve lock. The STX will accept data from the SPI bus and until the FIFO is full.
- In data mode data from the FIFO is transmitted to the ground station. Data is written to the FIFO at a suitable rate to prevent buffer under-runs.
- The STX will automatically switch off after 15 minutes if not commanded to switch off via I2C.

The STX is software defined and uses QPSK at variable rates nominally assumed to be up to 1 Mbps with 1/2, 1/4, 1/8 rates for enhanced telemetry and payload data utilizing the DVB-S encoding standard, but can be modified to provide up to 5Mbps in commercial frequencies which would make the High Res EO platform highly capable and able to download multiple images per orbit.

Figure 18 STX EM.

A 7 dBi directional S-band Patch Antenna is interfaced with the S-band transmitter and integrated into the base solar panel of the spacecraft. This antenna could be mounted on the underside of one of the deployed panels so as to not interface with the imaging payload. It is shown on UKube-1 in the image below:

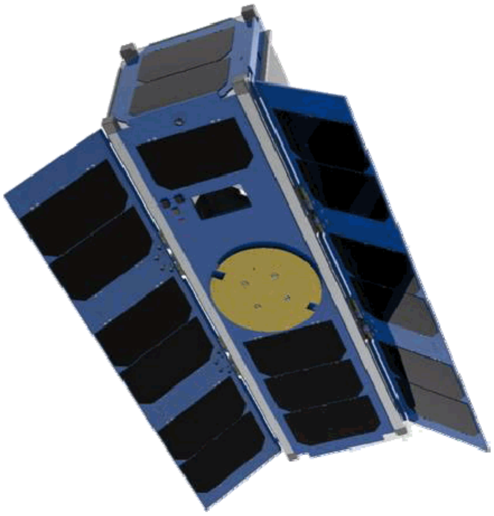

Figure 19 S-Band Patch Antenna on UKube-1.

CONCLUSION

The results of the studies have both indicated that it is feasible to use CubeSats to deploy high utility value EO payloads into space using a 3U CubeSat platform. The development need in terms of both payload and platform, where not insignificant, are closer to realization than may have previously been considered. In fact, the main technical challenges involved in, for instance the selection of a suitable IR sensor or the co-phasing of mirrors in the high resolution imager concept, already have solutions from other applications that can be employed.

Certainly, the findings of the studies are that both applications have merit for further investigation and development of the key technologies that will enable flight demonstration of the capability. The next steps are to developed and prove the payload and platform technologies to de-risk the implementation of these missions sometime in the next 2-3 years.

Due to the low volume, mass and cost of these spacecraft it becomes practical to have constellations of spacecraft, opening up the opportunity to start to significantly improve the temporal resolution of EO data from space. The prospect of 10s, if not 100s of very small Earth Observation spacecraft for science, commercial and military objectives is now closer to reality.

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