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How to cite:

Endicott, James; Holland, Andrew; Maseyk, Kadmiel; Fennell, Joseph; Morris, David; Jerram, Paul; Holland, Karren; Colebrook, David and Donchev, Anton (2022). TreeView: A small satellite supporting precision forestry for nature-based solutions in a changing climate. In: 4S Symposium 2022, 16-20 May 2022, Vilamoura, Portugal.

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Version: Accepted Manuscript

Link(s) to article on publisher's website:

<https://atpi.eventsair.com/QuickEventWebsitePortal/4s-symposium2022/website/Agenda/AgendaItemDetail?id=a2d04bfd-8b7b>

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TREEVIEW: A SMALL SATELLITE SUPPORTING PRECISION FORESTRY FOR NATURE-BASED SOLUTIONS IN A CHANGING CLIMATE

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ABSTRACT

The expansion of tree cover is a critical component of the path to net zero and the development of sustainable cities, but reaching this target will require extensive management of this resource. Through leveraging next-generation optical sensor technology and innovations across the payload and spacecraft development, TreeView will provide multispectral data at a ground sampling resolution on the scale of individual trees, providing measurement and monitoring capabilities from space at an unprecedented level.

TreeView has been funded through to a Preliminary Design Review (PDR) by the UK Space Agency's National Space Innovation Programme. This exciting mission aims to deliver a new perspective on urban green infrastructure in the UK and internationally, and assess the health of larger forest stands.

The mission has a challenging target of an end-to-end budget of £15M and to achieve this, cost, size, weight and power limits are imposed on the payload and spacecraft. Meanwhile, signal to noise performance, spatial and spectral resolution have been set to provide new and unique data not available from Sentinel-2 or commercial providers.

INTRODUCTION

TreeView is an Earth Observation mission that will achieve precision forestry from space, in the support of Nature-Based Solutions to tackle climate change.

The conventional approach in Earth Observation is to map and analyse forests as large, remote tracts of biomass managed in homogenous units known as 'forest stands'. To meet new political, environmental, social and commercial drivers, and maximise the benefit of tree planting for the UK and other countries, tree growth monitoring must fundamentally become more granular by considering the detail of individual plant diversity over smaller geographical footprints. Known as Precision Forestry, novel detailed asset management techniques are required to achieve this ambition.

A significant pillar of the UK's domestic response to the climate emergency and progress towards having net zero carbon emissions by 2050 is to significantly increase tree planting for carbon sequestration and storage. This Nature-Based Solution will aim to increase carbon capture and offset anthropogenic greenhouse gas emissions whilst aiding the recovery of nature and biodiversity.

The mission is designed to monitor trees and other ecosystems using a telescope and Time Delay and Integration (TDI) camera system operating in the visible and Near Infrared wavelengths of the

electromagnetic spectrum. Through multi-band imaging, spectral signatures of individual tree canopies will be obtained which will support tree classification and change detection such as early onset of disease, climate induced stress, infestations of pests, indicators of aging (senescence) and seasonal change (phenology). TreeView will also support the identification of tree loss through illegal or natural felling on a more granular scale than commonly used data from Sentinel-2 [1].

By using a combination of ground truth or validation information such as the Treezilla database [2], and well-documented and surveyed sites such as those from the UK National Forest Inventory (NFI), measured signatures will be correlated with previously identified trees. With an extensive database of validated signatures, TreeView will support a new level of species and habitat mapping outside of these sites, adding to the knowledge within the NFI, and the quantification and valuation of natural habitat for initiatives such as the Taskforce on Nature-related Financial Disclosure [**Error! Reference source not found.**].

This paper describes the proposed mission, satellite platform, payload, ground segment and the targeted data products that will be developed. The mission team have held a Preliminary Design Review and are preparing to continue work to progress towards a Critical Design Review when funding is available.

MISSION

TreeView is a New Space mission where innovation is being used to lower the costs and time to deliver the mission. In-Space Missions' cube-scale Faraday 2G platform, utilising proven sub-systems in a scalable satellite, is the baseline for the platform. The payload development is led by The Open University working with UK industry on the telescope, electronics and detector. The sensor is the latest Earth observation multispectral high-resolution sensor from Teledyne UK, designed to address very high-resolution imaging requirements. The ground segment data analysis will utilise an extensive database for validation of the data.

TreeView is designed to meet the following mission goals:

- map and identify the species of the UK tree population
- monitor 'green infrastructure' of cities and large towns of the UK
- generate early warnings of pest, disease and climate stress on tree populations
- compliment intensive forest monitoring sites with detailed spatial data (e.g. Alice Holt [4])
- provide space-based observation of large field-based climate change experiments (e.g. Birmingham Institute of Forestry Research (BiFoR) Free-Air Carbon dioxide Enrichment (FACE) [**Error! Reference source not found.**])
- image other countries and cities of interest (e.g. China, Australia, Brazil, Hong Kong, Singapore, Auckland) to support them in mapping and identifying tree species, and monitoring their urban green infrastructure
- to support agriculture and complementary carbon capture ecosystems (peatland)

In order to achieve these goals, the TreeView mission will require a satellite to operate in a Sun-Synchronous Orbit with an altitude of 500 km which has been chosen to provide the required resolution of individual tree canopies with the chosen payload telescope design.

The key parameters identified by the mission team during a feasibility study carried out in 2020 are summarised in the table below.

Table 1. TreeView mission parameters

Parameter	Target	Current	Rationale
Ground Sample Distance	2 m	2.2 m	Resolve individual trees
No. of spectral bands	6 - 10	8	Obtain spectral signatures
Bandwidths	10 – 40 nm	15 – 50 nm	Outcome of a trade-off
Swath	> 40 km	> 18 km (105 km)	To cover small cities in a single pass
Full UK Coverage	Once per year	Less than once per year	To establish a complete UK tree map
Repeat Coverage (spring – summer)	10 for target locations	> 10	To monitor change in the growing season
SNR	> 100	> 100	To obtain high quality science data

The evolution of the target values to the current values occurred during the feasibility study and then a subsequent development phase which concluded in the PDR in March 2022. The swath of the imager and instrument is much lower than the initial target, however, the lower value has been accepted since tiling multiple sensors in the focal plane was not possible within the target mission budget, and secondly, the ability to point the telescope across the ground scanning track provides an accessible swath width of 105 km. Through multiple passes larger continuous coverage can be achieved.

The second parameter where the mission priorities have evolved significantly is full UK coverage. This goal is now secondary to detecting change in target areas. It is clear that in the constraints of defining a high-performance micro satellite that a compromise has to be made. One route to achieving the goal of full UK coverage would be through a small constellation of TreeView satellites, however, this ambition would sensibly follow successful launch and operation of the first satellite.

Once launched and in-orbit, the platform and then the payload will be commissioned within the first three months. Once the performance of the payload and spacecraft has been verified, data will be released to the user community. The planned operational lifetime is 5 years from launch during which regular calibration and verification measurements will be made to track payload performance.

The mission analysis has considered both UK and global coverage. The major constraints on imaging the UK are the instances where the satellite crosses the UK land mass in the sunlit portion of the orbit and cloud cover. Analysis of UK coverage has been conducted in a series of corridors each 105 km wide corresponding to the accessible swath. The number of passes in a year varies between 18 and 31. With a loss of 50% of these imaging opportunities to cloud cover, a TreeView satellite would be able to image within the corridor every 3.5 to 6 weeks. A total of 6 passes is required to cover the full width of each corridor. It is clear that a single satellite will not be able to achieve both full coverage of the corridor and frequent repeat coverage of a target location within that corridor. For this reason, if only one satellite is operational, revisiting target locations will be prioritised over full coverage in the UK. The major constraint on global imaging is the downlink capacity, which is scalable with a

modest cost increase in downlink capacity, although frequent large-scale coverage lends itself to a small constellation approach.

The following sections of this paper provide an overview of the platform, payload, ground segment and data products.

PLATFORM

The spacecraft or platform relies on the modular Faraday-2G architecture, allowing flexibility of sub-systems to obtain the ideal balance of heritage, cost, and performance.

The requirement for high resolution multi-spectral data with a high signal to noise ratio led to a large aperture payload which was designed to fit on the platform's payload deck. The maximum payload deck area in the Faraday 2G architecture is 800 mm by 800 mm.

The outline of the platform and its underlining mechanical structure are shown in Figure 1.

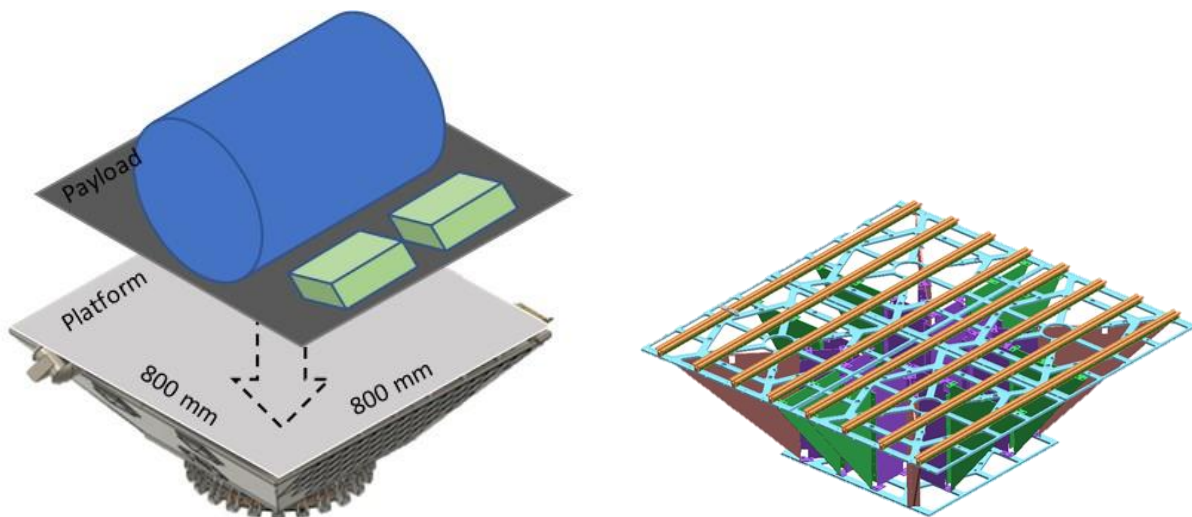


Figure 1. TreeView satellite concept with the payload and platform (left) and the mechanical structure of the platform (right)

A key part of the system is the CubeScale Platform Electronics (CPE). Along with the power system, this handles all the key safety and attitude systems. Redundant mission on-board computers and S-band telemetry and control transmitters are included. For the TreeView mission, two cold redundant payload data stores are used to store and move payload data between the payload Data Handling Unit and the dual redundant X Band transmitters.

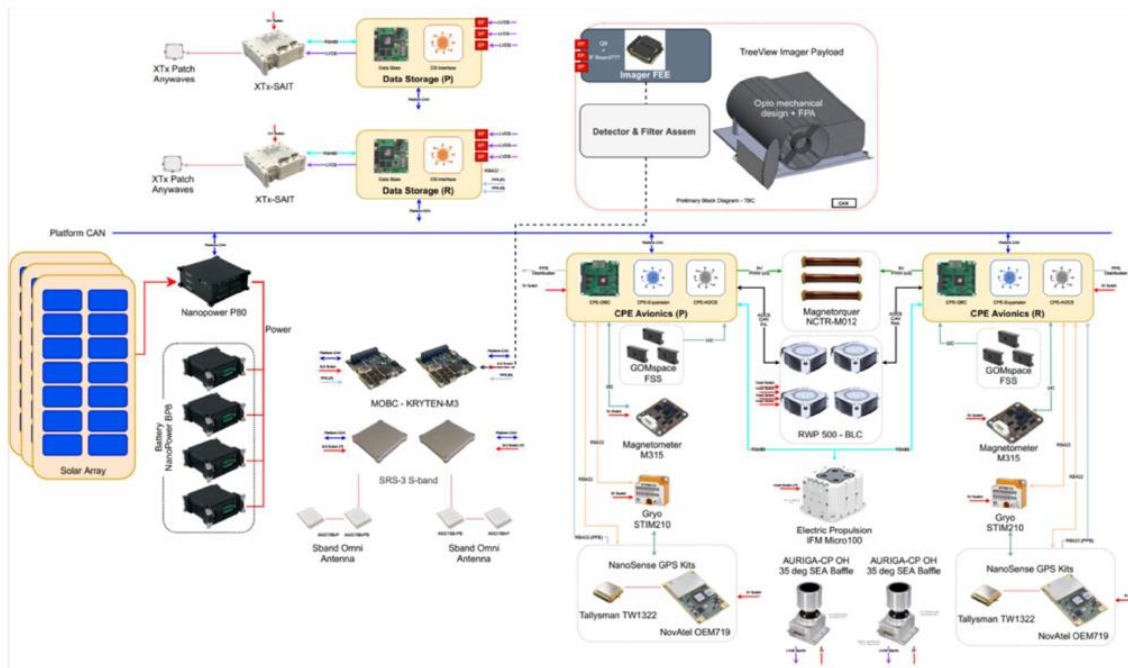


Figure 2. TreeView Spacecraft Block Diagram from In-Space Missions Ltd

PAYLOAD

The payload is an optical telescope with a suite of sub-systems to operate the image sensor, perform onboard data processing and compression, and to manage the payload temperatures to ensure stability. The telescope itself is a Richey-Chretien design with an entrance aperture of 300mm diameter toward ensuring high SNR of the multi-spectral imaging. The mechanical interface between the spacecraft and the payload may either be a rigid optical bench or the payload elements maybe directly attached to the interface rails on the payload deck.

The major payload elements are the telescope, electronics, and sensor, which are mounted in the focal plane assembly, and the heating and cooling, which is comprised of the radiator, resistive heaters, and temperature sensors. Within the electronics there are three main functions: the camera electronics to drive the sensor, perform data stream de-interlacing and provide some limited storage, the Data Handling Unit including the payload data store, which will provide medium term storage of the images generated, compression, and functions to aid downlink such as thumbnail generation plus image quality classification, and the Payload Monitoring and Control unit, which will handle the thermal monitoring and stabilisation of the payload.

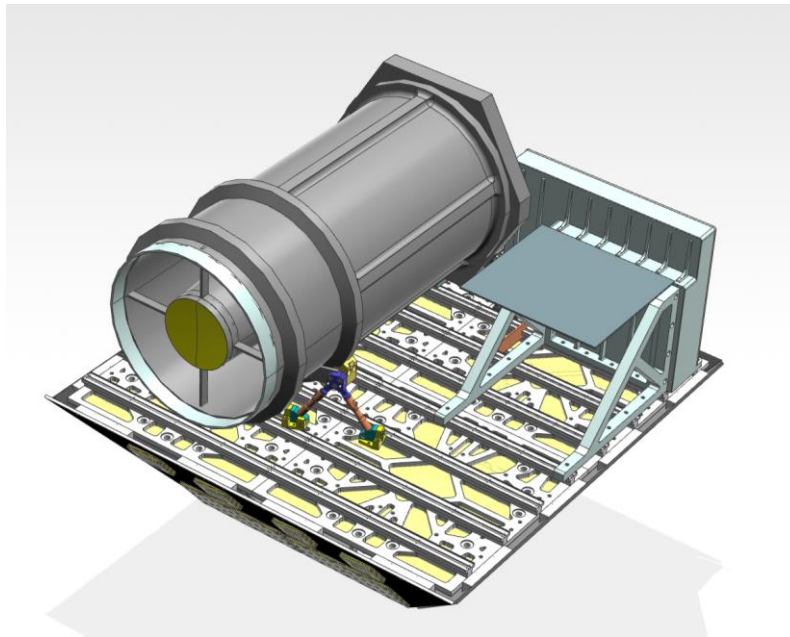


Figure 3. The payload on the payload mounting deck of the spacecraft with the telescope in grey with a light blue entrance aperture, a grey-blue radiator, and electronics boxes visible to the righthand side. The optical bench is not included in the figure.

Within the payload, wavelength selection for the multispectral bands will be via narrow band pass filters. Originally a target science requirement of between 6-12 spectral bands was set, but later this was refined to be a selection of 8 bands as shown in Figure 4. The number of bands was a compromise between obtaining additional spectral information and increasing the volume of data to downlink, whilst also considering the physical integration of filters on the sensor. The current selection of spectral bands has been chosen to enable the retrieval of key vegetation indices and to obtain the spectral signatures which through time series measurements will enable tree classification and detection of signs of stress, disease, infestation, changes in health, activity or phenology.

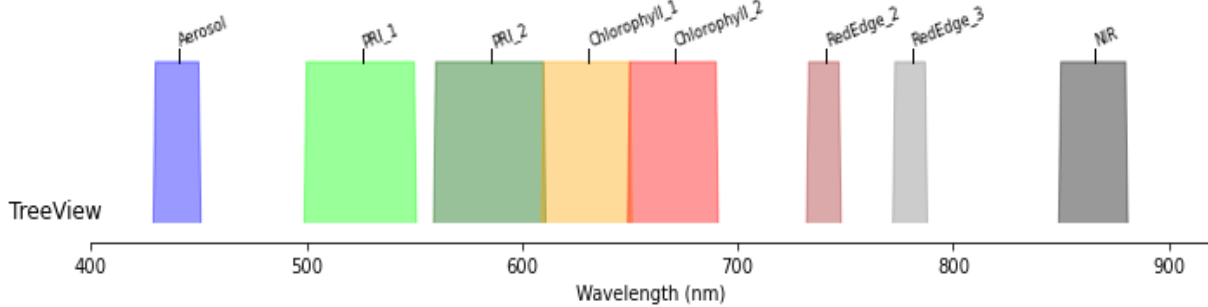


Figure 4. The current selection of multispectral bands for the TreeView mission

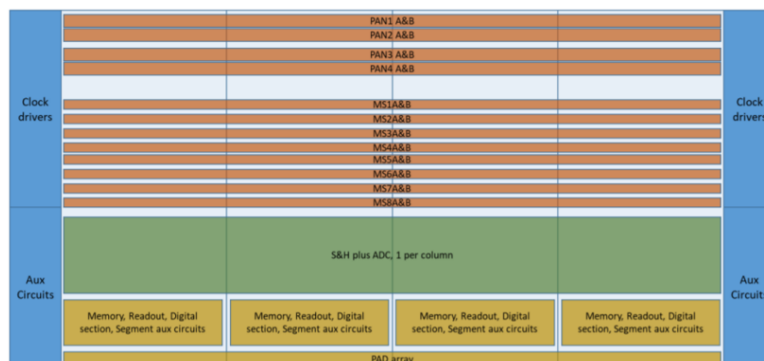


Figure 5: Schematic of the CIS125 TDI CMOS sensor, with 4 PAN and 8 Multi-spectral sub-arrays

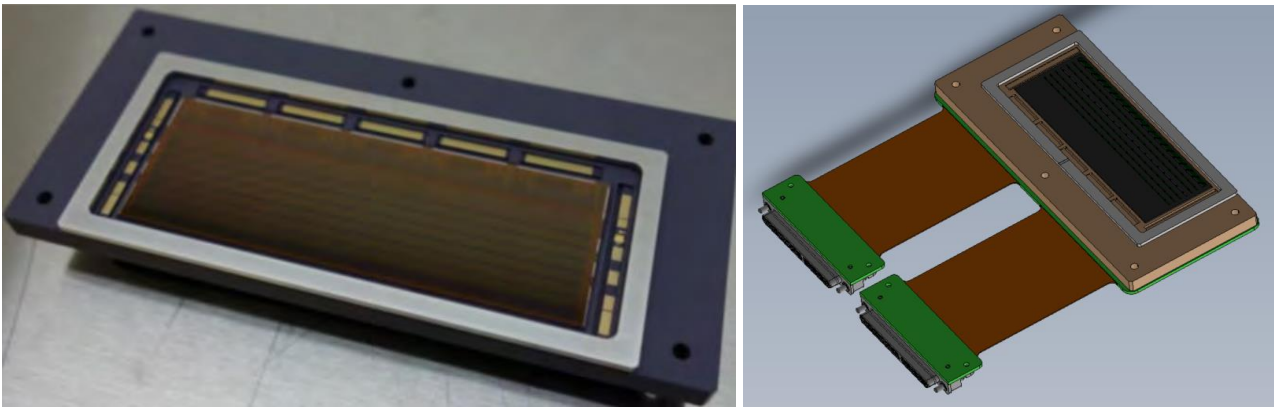


Figure 6: New TDI CMOS image sensor from Teledyne e2v in its ceramic evaluation package (left) together with its flight packaging concept (right)

The image sensor to be used for the mission is a new development from Teledyne e2v referred to as the CIS125. In the past, the CCD was used for time-delay-integration applications, however this new sensor uses CCD-in-CMOS technology to perform the same imaging function of the CCD approach, whilst integrating much of the functions normally designed into discrete electronics of; sensor sequencing, signal digitisation and multiplexing into the CMOS electronics on the same silicon die, thereby reducing the overall system power, mass and complexity. A schematic of the new CMOS image sensor is given in Figure 5. The sensor contains 8 separate multi-spectral (MS) arrays plus 4 pan-chromatic (PAN) arrays, with A+B pairs for each sub-array.

Figure 6 shows a photograph of the CIS125 sensor from Teledyne e2v in its ceramic carrier version (left) and the CAD model of how this would be integrated with flex circuits and connectors to the proximity electronics by XCAM.

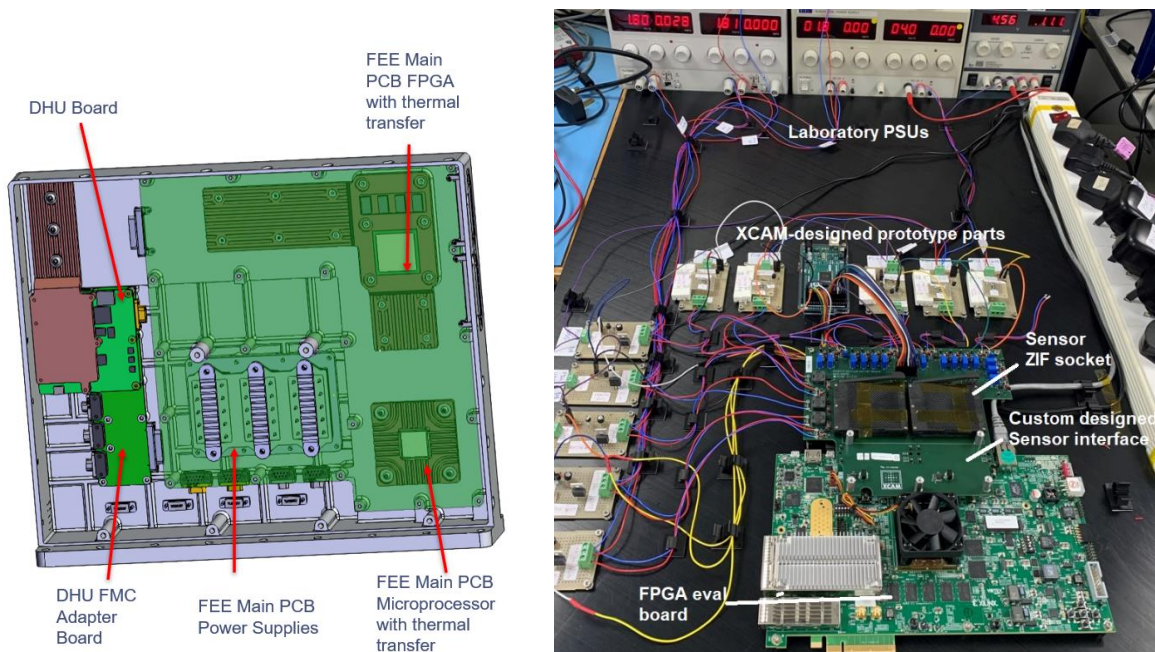


Figure 7: Payload control electronics concept from XCAM (left) with the prototype system developed under the current phase of the work to evaluate the new sensor (right)

Figure 7 shows the design for the payload control electronics (left) together with the flat-sat system prototype developed under the current phase of the work to help de-risk the camera system which is

reliant on a totally new sensor from Teledyne e2v. The payload control electronics has the key sub-systems of sensor front end electronics (FEE), payload data handling unit (DHU) and instrument thermal management. The FEE is responsible for operation of the image sensor, together with de-interleaving the returned data to produce conventional TDI image data (for each of the 8 colour channels) and to provide local storage. The image data is transferred to the DHU board which provides long-term storage of the images for subsequent transfer to the spacecraft DHU for telemetry. The payload DHU also can provide quick-look thumbnail data and perform lossless image compression on the data to maximise the usage of the telemetry budget.

GROUND SEGMENT

Following the launch, In-Space Missions' Faraday service operations architecture will be used for satellite command and control. The spacecraft will be operated from the Faraday operations centre utilising a commercial ground station network to communicate with the spacecraft. The operations centre will not only operate and ensure spacecraft safety but will be a single point of contact with the mission operations team for all tasking enquires and data transfers.

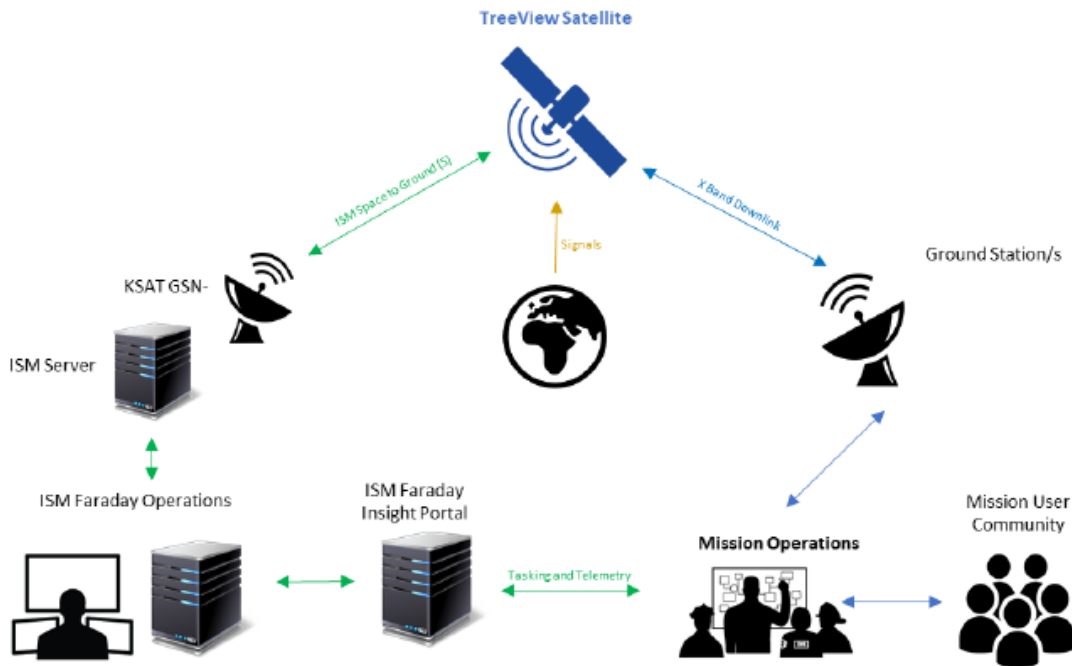


Figure 8. TreeView Mission Architecture

Data received by the Ground Station would ideally be transferred by a short-distance dedicated peer-to-peer secure private 4-core optical fibre network to a designated data centre. The latter ideally should be located either in the satellite ground station or in an adjacent building. A RAID (Redundant array of Independent Disks) or alternative back-up system should be implemented to prevent any loss of data. The approach to managing data duplication and bloat is yet to be defined, but the mission team are conscious of the need to be economical and responsible.

The space segment will transfer image data, payload monitoring and housekeeping data, spacecraft pointing, timing and location data to the mission ground segment. This data will be processed and analysed with inputs such as very high-resolution reference imagery, cloud cover data and digital elevation models within the ground segment data analysis and processing pipeline. The first level data released from the pipeline will be geometrically and radiometrically corrected and will be

available to the remote sensing community. Level 2 atmospherically corrected data will be released to a broader Geospatial Information community and finally Level 3 derived data products will be released to wider scientific, government and commercial users. These levels are illustrated in Figure 9.

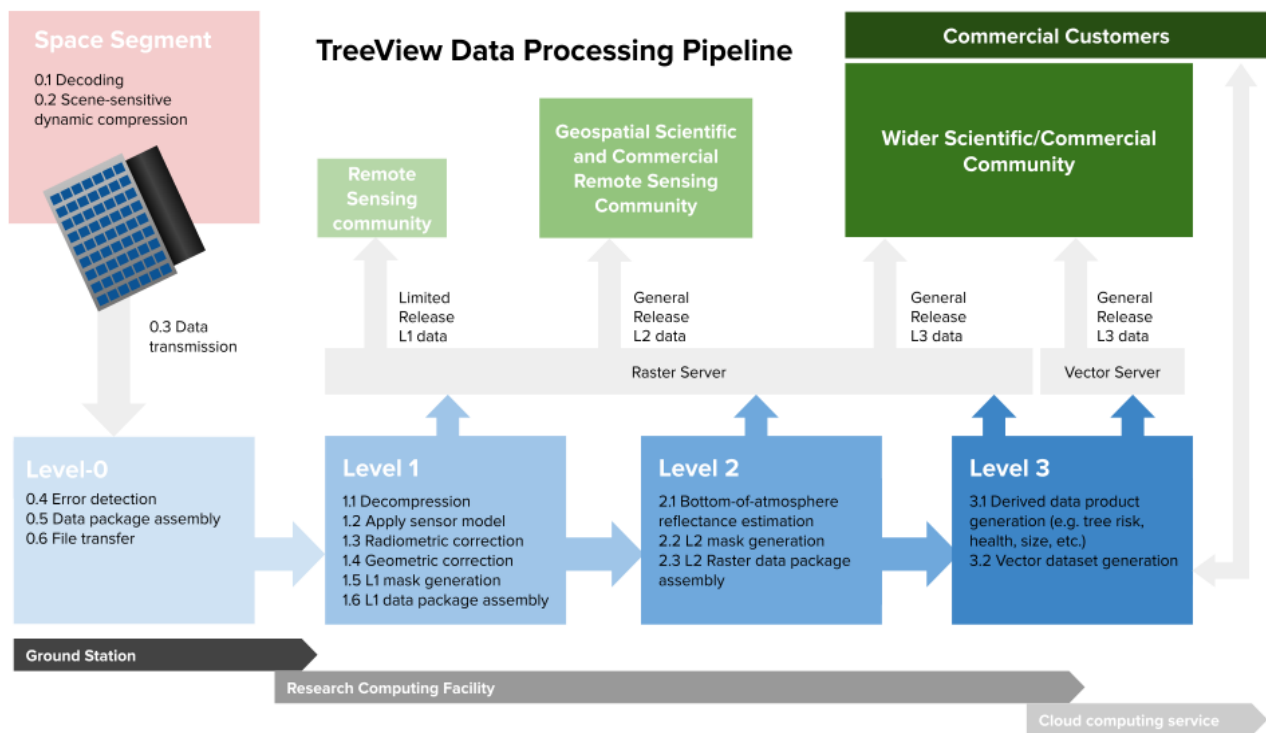


Figure 9. TreeView Data Processing Pipeline

Computing facilities will be required for the data processing steps identified in Figure 9. One option is high performance computational facilities managed by the TreeView Mission. An alternative is to use a commercially provided service. Another final option could involve UK research infrastructure such as the Centre for Environmental Data Analysis and JASMIN facility. The mission team would prefer to reduce the transfer of large datasets and to optimise computational, human, and time resources available. With a view to international collaboration on the mission, a model might be that data generated for a partner nation or international organisation would be stored and processed in their infrastructure.

DATA PRODUCTS

The data products that will be produced by the mission team with partners or by the TreeView user community or customers will range from indicators of tree health to more granular information on species and reforestation of the UK and other territories in their steps to offset carbon dioxide emissions and reduce the levels of atmospheric CO₂. The finer spatial resolution of TreeView will support the detection of illegal felling and provide monitoring of encroachment onto infrastructure and other habitats.

CONCLUSIONS

The TreeView mission concept which is under development by an academic-industrial consortium in the UK has been described. With 8 MS colour channels, coupled to a 2.2m GSD and 18km swath width, the mission will enable characterisation of trees in both urban and rural environments. With approximately ~10 site re-visits per year, the mission will support tree classification and through long-term monitoring will enable change detection such as early onset of disease, climate induced stress, infestations of pests, indicators of aging and seasonal change. The mission has just passed PDR and, subject to funding, is about to move into CDR progressing through phases B/C/D towards realisation of this demonstrator mission.

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