**Title: Cubesat constellation for monitoring and detection of bushfires in Australia**

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**( X ) We apply for Student Prize.**

## 1. Need

Australia's periodically hot, dry climate is a catalyst for some of the largest and deadliest bushfires in modern history, with more people in Australia injured from bushfires than all other natural disasters combined. The combined economic and environmental damage of bushfires over the period from 2000-2013 is estimated to be $2.6 billion [1]. Currently, large weather satellites are used to detect bushfire hotspots. The Himawari-8 satellite is capable of providing updated active hotspot data every 10 minutes, but with a 2km spatial resolution. Other satellite systems provide less timely data at ~1km resolution. Fire services would benefit from frequent, higher resolution data to determine the precise location of active hotspots. This data could be integrated with topographical and environmental data to aid in predicting the outcome of a fire at an early stage. For example, knowing what side of the road a fire is on can determine whether the fire can advance up a neighbouring hill, and hence whether a nearby town will be affected. Therefore, there is a need for a constellation of bushfire monitoring microsatellites that can provide timely, higher resolution thermal imaging, and at a lower cost compared to existing satellite and ground systems.

## 2. Mission Objectives

*Primary Objective*

1. Establish a bushfire detection and monitoring system providing medium resolution imagery (a minimum of 100m GSD is required) with a useful repeat time (maximum of one hour between availability of satellite images is considered acceptable) within target areas in Australia.

*Secondary Objective*

2. To provide thermal imaging services for other environmental applications or to other countries.

## 3. Concept of Operations

***Space Segment:***

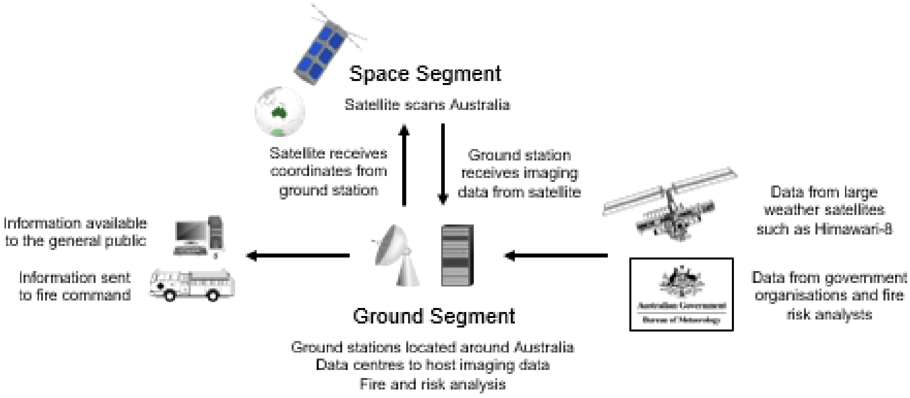
The space segment will consist of a constellation of 3U Cubesats in Low Earth Orbit. The constellation will be configured such that imaging of target will occur with hourly frequency during the day (when fires are most likely to occur) and lower frequency at night time. Imaging will occur in the 2.2uM wavelength, as this is suitable for detection of hot glow from fires and is relatively transparent to cloud cover [2].

***Ground Segment:***

Approximately 9-10 ground stations will be situated across Australia. They will serve two core functions:

*1) Directing imaging*

Supercomputer simulations at CSIRO can predict regions at high risk of bushfire hotspot formation with 91% accuracy using weather, environmental and topographical data. These locations will be uplinked to the approaching Cubesats as prioritized monitoring targets using ground stations. This will allow for targeted scanning of high risk regions for potential early detection of fires. Additionally, if an active fire hotspot is detected by Himawari-8 then the location will be uplinked to approaching Cubesats as an urgent location for medium resolution imaging.




*2) Downlink & usage of images.*

As the constellation passes over the uplinked coordinate ranges, they will capture medium resolution thermal images. These will then be downlinked to ground stations using S-band transceivers. These images will then be analysed by the ground command for preventative, predictive or direct action.

## 4. Key Performance Parameters

1. Better than 100m spatial resolution at the 2.2uM wavelength. This enables medium resolution imaging, at the minimal level required for precise hotspot tracking and fire monitoring.
2. Better than 1 hour repeat time between image availability. This can allow initial images of small developing fires to be obtained prior to reaching a stage of uncontrollable growth. For developed fires, the frequency is sufficient to monitor changing fire direction and advancement to urban areas.
3. 85% percentage ground coverage of high risk, populated areas and national parks. Populated fire hotspot regions are key coverage areas and are prioritized over central Australia and the outback.

## 5. Space Segment Description

***Overview of Components:***

| Component | Notes | Mass (g) | COTS/Custom |
|---|---|---|---|
| **General** | | | |
| 3U Cubesat Structure | 3U Kit Structure (Pumpkin) * 2 | 190 | COTS |
| ADCS | IMI-100 ADCS | 980 | COTS |
| Solar Panels and Lens Shade | From Pumpkin/Clyde Space | 900 | Custom |
| Cables and misc. | Misc. | 150 | COTS |
| Power Supply | 15W EPS + Battery | 300 | COTS |
| **OBDH** | | | |
| CPU Board & Mass Storage | Cool LiteRunner-LX800 w/ CF Storage | 150 | COTS |
| S-Band Transceiver | | 80 | COTS |
| Antennas | | 150 | Custom |
| Flight Module | Cubesat Kit FM430 | 90 | COTS |
| **Imaging Payload** | | | |

| | | | |
|---|---|---|---|
| Sensor (& cooler) | Quazir HD Hot MWIR Camera Core | 450 | COTS |
| Lens | f/4, 200mm IR Lens | 600 | COTS |
| Imaging structure | Custom mounts and interfaces | 300 | Custom |
| | **Total** | **4340** | |

***Imaging Payload:***

The imaging payload uses off the shelf nBn infrared sensor (Quazir HD Hot MWIR Camera Core) technology from IRCameras, and will image using the 2.2uM wavelength. The sensor core has an operational range of -40°C to 71°C and has an in built Sterling cooler. While this system provides much higher resolution (pixel pitch of 12 μm) than other more mature technologies (HgCdTe), it has yet to be used in a space mission, so extensive environmental testing will be required prior to usage [3]. The system will be integrated with a f/4 200mm IR lens of 110mm diameter (the maximum possible diameter for the Cubesat).

The Rayleigh criterion gives the resolving power of the lens for a 2200nm wavelength as $R = (\lambda \times 1.22)/\mathrm{D}$, providing a pixel resolution of 23uM. Ground resolution is calculated with the following expression (where p is the resolution limited pixel size, A is altitude and FL is focal length): $GSD = (p \times A)/FL$. At an orbit altitude of 574km, this sensor provides a GSD of 62m and a swath size of approximately 79.5km x 63.6km.

***General***

*ADCS*

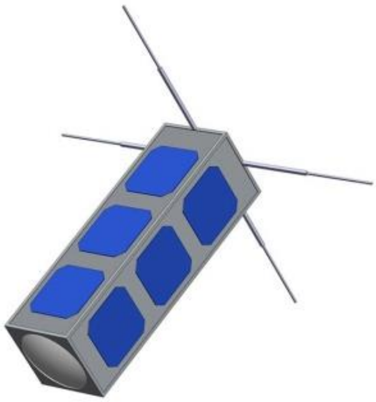
Accuracy is required for the imaging of specific earth based targets. This also allows for the use of more directional antennas with lower power usage requirements. A number of COTS systems could meet this specification, including the IMI-100 system (used by the MISC low cost imaging satellite) which provides 3-axis pointing with 1 degree accuracy [4].

*Solar Panels*

A standard 3U deployable solar panel kit (and lens shade) with body panels from Pumpkin will be used and this is expected to provide 21W peak power.

*Structure*

The structure will be comprised of a standard 3U Cubesat kit from pumpkin. The structure will have dimensions of 34cm x 10cm x 10cm.



***OBDH, Operations and Power***

*Image Capture*

Coordinates will be uplinked from ground systems or satellites such as Himawari-8 and the Cubesat will then orient the camera towards these coordinates using the ADCS. Images taken are temporarily stored on-board (64GB storage) before being downlinked.

*Downlink*

S-Band stations will provide high downlink speeds of approximately 1Mbps. Approximately 100-200 2MB images are expected to be captured per day. Downlink could be achieved using just 9-10 stations positioned throughout Australia. On-board processing of images will use the signal processing unit built into the nBn sensor to prioritise any key images of potential fire hotspots.

*Power*

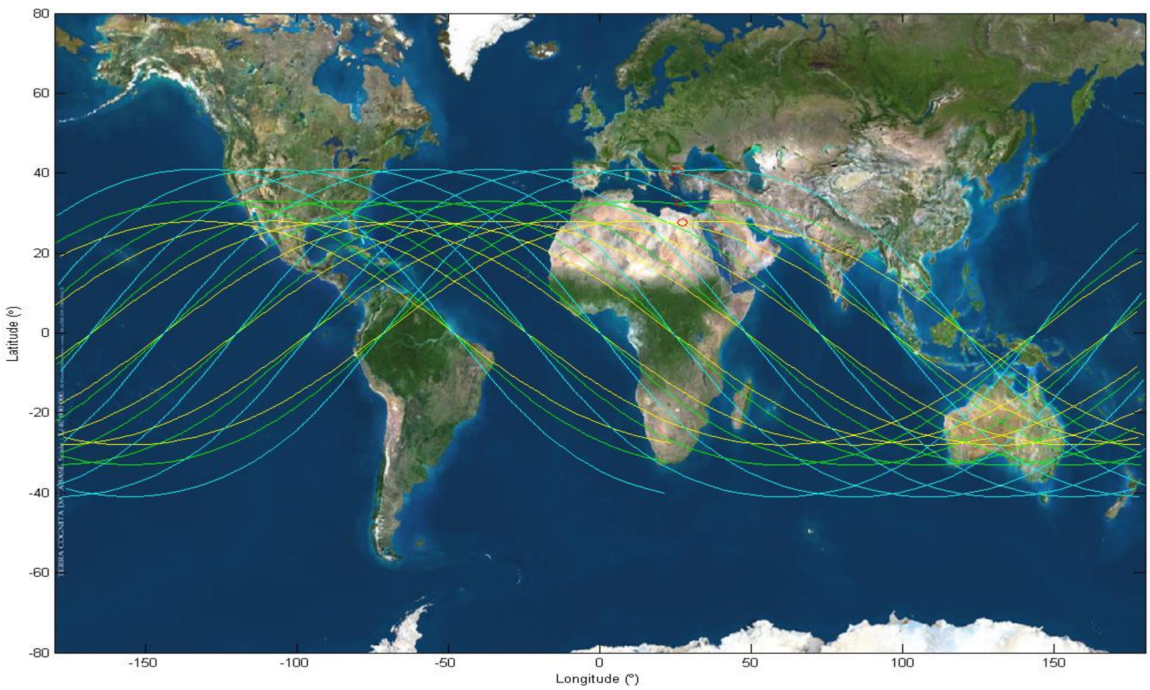
| Component/s | ADCS | CPU + GPS + FM | Communications (Uplink/downlink) | Sensor, Cooler & Processor |
|---|---|---|---|---|
| Power (W) | ~3W | ~1W | ~6W | ~9W |

A preliminary analysis of power requirements reveals that it is not possible for image capture and downlink to occur simultaneously. It is expected ~12W is required for imaging and ~10W required during downlink. Power can be generated at ~20W during downlink, but only ~14W during image capture (due to lens shade extension).

## 6. Orbit/Constellation Description

A constellation of 12 satellites will be used as this minimises repeat time while adhering to the mass budget of the mission. Fires are much more likely to ignite and spread quickly during hot, dry weather [5] (i.e. during the middle of the day) so the orbits are designed such that the dwell time over the Australian mainland occurs during times of high fire risk.

In order to maintain daytime coverage schedule, the satellites will orbit with a period of 96 minutes with an optimal operating altitude of 574km. In order to reduce repeat time without compromising coverage, the satellites will be deployed in three different inclinations, 41°, 33° and 28° with 4, 5 and 3 satellites in each inclination with delay times between each satellite such that the final satellites path




12 Hour Ground Track. Cyan - 41°, Green - 33°, Yellow - 28°

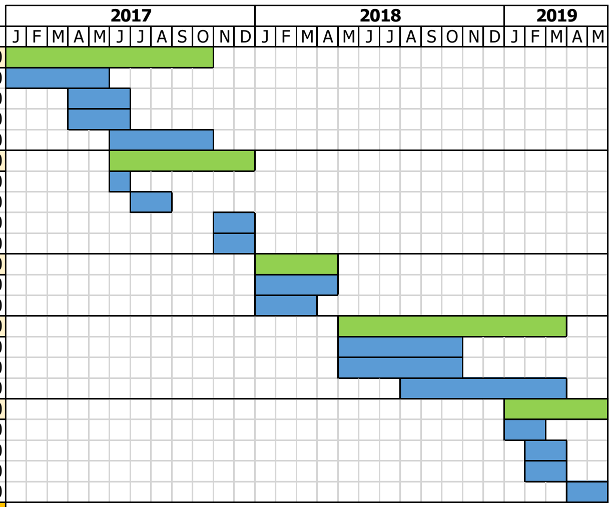
Red Circles indicate starting position of ground track.

Assuming an orbit decay rate of 2km/month and a lifetime of 18 months, the satellites will launched into LEO with altitude of 592km and over 18 months this will decay to 554km whereby the satellites will deorbit.

## 7. Implementation Plan

The implementation plan, project schedule and preliminary cost breakdown is outlined below:

| Implmentation Plan | Cost |
|---|---|
| **Design Phase** | 300,000 |
| Preliminary satellite and mission design | 80,000 |
| Structure feasibility study | 30,000 |
| COTS feasbility study | 30,000 |
| Detailed satellite and mission design | 160,000 |
| **Development Phase** | 2,150,000 |
| Establish ground segment centre | 100,000 |
| Procure ground segment equipment | 250,000 |
| Manufacture custom components | 360,000 |
| Procure COTS components | 1,440,000 |
| **Integration and Assembly** | 90,000 |
| Satellite systems integration | 60,000 |
| Ground systems integration | 30,000 |
| **Testing** | 220,000 |
| Satellite testing | 50,000 |
| Ground communications testing | 50,000 |
| Complete systems testing | 120,000 |
| **Launch** | 2,040,000 |
| Establish launch command | 60,000 |
| Establish ground command | 100,000 |
| Establish space command | 80,000 |
| Launch | 1,800,000 |
| | 4,800,000 |




The estimated cost for the mission design and launch for 12 satellites is approximately AU$6 million with a 25% margin for error. This includes the cost of facilities and resources (approximately $30k per ground station), 10 engineers over 2.5 years, and approximately $300,000 per satellite for manufacture and launch. The ground command will be situated at CSIRO and they will provide data to other government agencies and fire/risk analysts around the country.

### *Major Project Risks*

Major project risks outlined in an increasing risk level:

1. Ground Communications Failure (data centre and ground communications uplink)
2. Launch Failure (constellation requires complete successful launch)
3. Imaging Systems Failure (lens and sensor)
4. Space Communications Failure (space communications downlink and onboard storage systems)
5. ADCS and Satellite Orbit Failure (complete malfunction and failure of the satellite system)

### *Decay and Deorbit*

Our LEO orbits allows for passive deorbiting. Larger imaging satellites can carry risks during deorbit due to their mass and possible fuel toxicity. Satellites in the proposed mission do not carry those risks.

## 8. References


[1] J. W. Handmer, S. Dovers, J. W. Handmer, and Ebooks Corporation. (2013). Handbook of disaster policies and institutions: improving emergency management and climate change adaptation (2nd ed.).

[2] Lentile, L., Holden, Z., Smith, A., Falkowski, M., Hudak, A., & Morgan, P. et al. (2006). Remote sensing techniques to assess active fire characteristics and post-fire effects. *International Journal Of Wildland Fire*, *15*(3), 319.

[3] K., N., Dat, R., & K., A. (2013). Advances in Infrared Detector Array Technology. Optoelectronics - Advanced Materials And Devices.

[4] Andrew, K. (2014). MISC™ – A Novel Approach to Low-Cost Imaging Satellites. In 22nd Annual AIAA/USU Conference on Small Satellites.

[5] Australian Institute of Criminology – The time of day of bushfires in Australia. (2016). Aic.gov.au. Retrieved 11 April 2016