Use-Case-Driven Systems Engineering for a Global Wildfire Early-Detection & Monitoring CubeSat Constellation

ABSTRACT

Wildfires cause devastating losses in human **lives, infrastructure** and forests as well as considerable **financial costs for suppression and rebuilding**. Imagining, designing and building a **CubeSat constellation to counter and prevent** such catastrophic events in the near-future has become possible through recent technological advancements.

As initial systems engineering **design requirements** have been derived through **interviews** with various potential user stakeholders, **research** based on publications and **calculations**.

The results presented are **trade-off design values** for the needed main parameters **spatial resolution (200 m/pixel), revisit times (30 minutes)** and **spectral multiband resolutions** (at least dual infrared - **MWIR & LWIR** - with additionally NIR or VIS), as well as additional derived sensing and user requirements.

PROBLEM: CLOSING THE IR-GAP HIGH REVISIT TIME & RESOLUTION

Existing Satellite Solutions:

GEO-Satellites
+ very high temporal resolution
- only one specific field of view
- limited spatial resolution (for example 2 km/pixel for NASA GOES-R 16 or GOES-S 17)

LEO-Satellites
+ large coverage (dependant on orbit)
- limited temporal resolution (for example 4x / day for MODIS two-satellite system)

A **CubeSat constellation** with advanced **miniaturized infrared sensors** in **lower earth orbits** could **close the wildfire observation early-detection and monitoring gap**, support further research of wildfire formation and behavior and could potentially reduce the severity and consequences of wildfires globally in the future.

USER INTERVIEWS: PARTNERS

1. Gernot Rucker, ZEBRIS/firemaps.info (**Consultancy on fire detection & management**, online platform for sat-data firemaps)
2. Michael Reffgen, **University Professional Fire Brigade**, TU Munich
3. Lukas Weber, **Air Traffic Controller**, Airport Stuttgart
4. Ronald Richter, **Professional Fire Brigade Karlsruhe**, Head of prevention unit
5. Gerrit Darkow, **AON Insurance**, Team Leader Aon Risk Solutions
6. Dr. Doris Klein, **German Remote Sensing Data Center** of the German Aerospace Center (DLR)

TWO USE-CASES: DETECTION & MONITORING

1. Early-Detection
Initial warning about a new wildfire in a certain area with a certain size as fast as possible after fire ignition

2. Continous Monitoring/Mapping
Most continuous possible observation of an already detected wildfire to gain actionable insights into its properties (growth rate, movement direction & velocity, emitted radiative energy, ...).

SENSING: SPECTRAL RESOLUTION

Infrared remote sensing
- Satellite-based: 700 nm - 14 µm [2]
- Limited by atmospheric window
- Wildfires show dominantly temperatures between 650 K to 1,500 K [3]
- Theoretically best detectable from 2-5 µm (Blackbody radiation maxima)
- Fire radiance only stronger or equal to solar reflections for MWIR & LWIR [3]
- MWIR (3-5 µm) ideal for fire detection because of greatest intensity difference compared to surrounding vegetation [3]
- False-Pixel avoidance: to distinguish fires from solar glints, a second band below 1 µm (NIR/VIS) is required [4]
- For detailed (sub-pixel) fire event size analysis, LWIR (8-14 µm) is required [5]

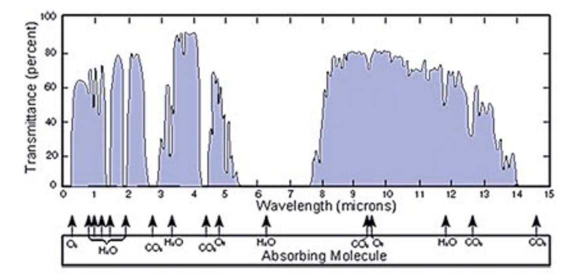

Figure 1: The atmospheric window [1]

A wildfire system capable of reliable fire-detection (distinction from false alarms by solar reflections) and sub-pixel measurements shall have bi-spectral infrared (MWIR between 3-5 µm and LWIR between 8-14 µm) and VIS or NIR sensing capabilities.

SENSING: SENSITIVITY

- Many IR satellites optimized for land surface temperature measurements, not able to detect wildfires due to limited maximum sensing temperature [6]
- Important characteristic: Fire Radiative Power $P_{FIRE\_RADIATED} = \sigma * (T_F^4 - T_B^4) * A_F$ (Stefan-Boltzmann constant, temperatures fire & background, area fire)
- 50% of wildfires are lower power events < 8 MW FRP, currently only detectable by BIRD, BIROS & TET-1 satellites [3]

Temperature range of IR measurements shall be from 250 - 1,200 K.
Fire events shall be detected from 2 MW FRP on.

SENSING: SPATIAL RESOLUTION

- Parameter: meters per pixel (dependant on orbital altitude, pixel size on chip, optical system) [7]
- Minimum archievable IR spatial resolutions by factor 25-225 (MWIR-LWIR) bigger than for visible spectra at same aperture size due to physical diffraction law (Rayleigh-criterion)
- Sub-pixel size events are detectable, if radiance difference between fire and environment is greater than background sensor noise (NEDT) [3]
- Larger sub-pixel size events are quantifiable with sub-pixel area estimations based on probability and local environmental values with Dozier's bi-spectral model [8]

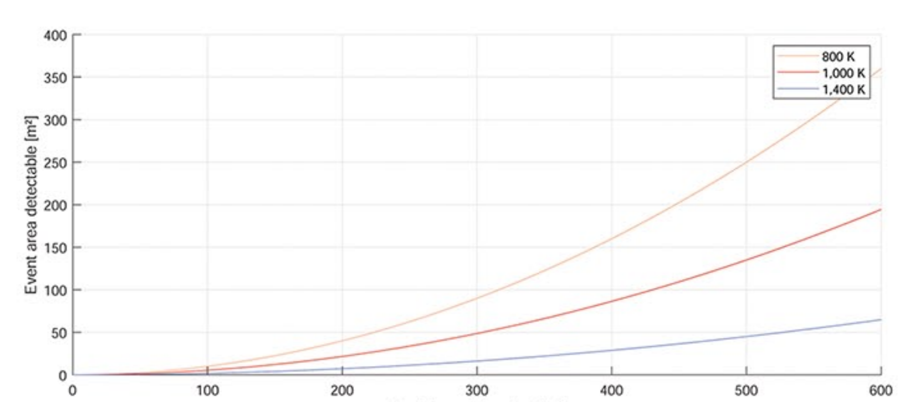

Figure 2: Spatial resolution vs. detection area size for different fire temperatures

The ground pixel resolution of all bands shall have at least 375 meters / pixel .

SENSING: TEMPORAL RESOLUTION

- Revisit time = time interval between two overpasses of certain location from one satellite or next satellite (for a constellation)
- Theoretically best possible revisit time for one satellite: approx. 90 minutes (400 km orbit)
- Many current IR satellites have revisit times > 12h
- With a constellation of many satellites, custom revisit times < 90 minutes are possible
- Case Early-Detection: revisit time directly influences warning time
- Case Monitoring: revisit time defines the unobserved firefront advance distance based on wildfire rate of spread

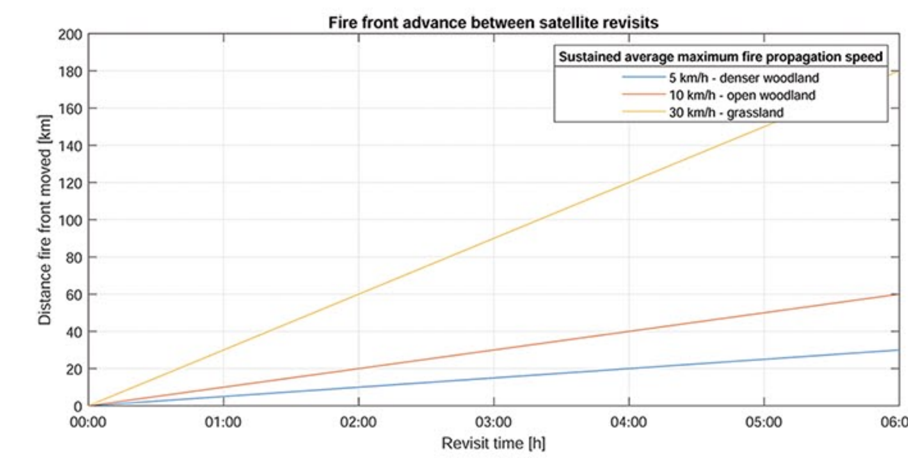

Figure 3: Approximate fire front advance between satellite revisits for maximum sustained fire propagation speed for different vegetation

The system shall have a revisit time of 30 minutes for every location in the specified observation region.

VISION: GLOBAL WILDFIRE EARLY-DETECTION & MONITORING CONSTELLATION BY 2022

The startup Orbital Oracle Technologies GmbH (OroraTech) is creating a system that automatically detects and monitors wildfires around the globe, significantly reducing damage and air pollution.

To achieve this goal, the company is building a constellation of nanosatellites equipped with a unique thermal infrared camera, monitoring every point on Earth several times per hour.

- Spin-off from Technical University Munich
- Research satellite platform operational in space
- Project started in early 2017, Company founded in Sep. 2018
- 4 founders, 20 employees in total
- Funding: €1 million from research grants and private investors

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