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NUCLEAR ENGINEERING
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Nanoracks

Multi-modal Remote Surveillance of Localized Processes Using Cube Satellite Platforms: Phenomena, Feasible Architectures, and Sensor Considerations

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ETI Annual Workshop, October 6th – 7th, 2020

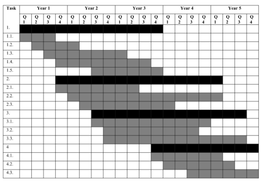
Project Description

Cube satellites (CubeSats) provide a unique platform for monitoring localized processes anywhere within the Earth's surface or atmospheric levels regarding nuclear security.

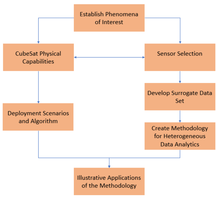
- Areas of interest can be targeted at certain times on an on-demand basis, "stash and deploy"
- CubeSats equipped with adequate sensors and data analytics capabilities can create an autonomous characterization surveillance method for phenomena of interest
- Advantageous over conventional satellites because of cost and simplicity

Timeline

- Task 1: CubeSat-based global surveyor architecture development
- Task 2: Specification development for a CubeSat-based global surveyor
- Task 3: Computational and experimental program based on surrogate and simulated data sets demonstrating capabilities of the orbital surveyor platform
- Task 4: CubeSat design and data analysis towards a future demonstration launch program



CubeSat-based Surveillance Platform Development



Phenomena and Signatures

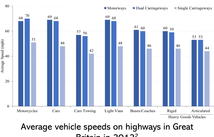
- Types of phenomena of interest for observation will determine CubeSat physical architecture and sensors
- Due to life-time of CubeSats in orbit, the surveillance system is best suited for events of immediate interest on an on-demand and short-term periodic basis
- Focus on nuclear fuel cycle

Phenomena
- Vehicles of Interest
  - Automobiles and Airplanes
- Facilities and Infrastructural Emergencies of Interest
  - Blackouts and Fires
- Construction and Mining Events of Interest

Signatures
- Dimensions
- Speeds
- Emissions
- Temperatures
- Other

Dimension	Value
Height	1.41 m – 2.12 m
Length	2.70 m – 5.40 m
Width	1.48 m – 2.07 m

Minimum and Maximum Dimensions for all new vehicles sold in Europe[1]



Average vehicle speeds on highways in Great Britain in 2012[2]

Automobile Emissions[3]
CO_2
CH_4
CO
N_2O

Average Operating Temperature of Automobiles[4]
90-105 °C

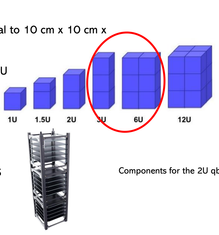
CubeSat Platform Analysis

CubeSat Architecture

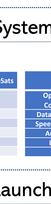
- CubeSats are measured in units of U, 1U is equal to 10 cm x 10 cm x 10 cm cube with a mass close to 1 kg
- Sizes range from 1U to 12U
- Most common and versatile form factor: 3U & 6U
- Allows for the use of COTS components

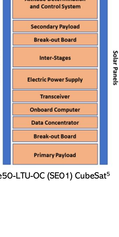
Major CubeSat Components

- Payload (Sensor)
- Power Supply
- Transceiver
- Solar Panels
- Attitude Control System
- Antennas
- Onboard Computer and Circuitry



COTS





Components for the 2U qbee50-LTU-OC (SE01) CubeSat[5]

CubeSat System Options

1 CubeSat vs Constellation

Attribute	1 CubeSat	Constellation of CubeSats
Higher Characterization Accuracy Through Sensor Diversity		✓
Lower Cost	✓	
Increased System Security		✓
Robustness Through Sensor Redundancy		✓
Simplicity	✓	
Longer Overall Access Times to Ground		✓

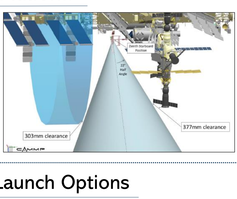
Communications Options

	Ground Station Only	Inter-CubeSat	Additional Satellite Relay
Operational Complexity	Moderate	High	High
Data Flow Steps	High	Moderate	Moderate
Speed to Surface	Moderate	High	High
Autonomy	Low	High	High
Lifetime	High	Low	High
Cost	Moderate	Moderate	High

CubeSat Launch Platform

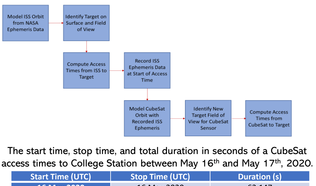
International Space Station (ISS)

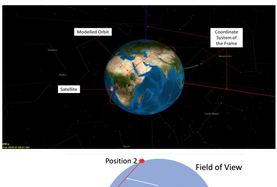
- NanoRacks Deployer
- Lack of propulsion on CubeSat
- ISS inclination and period



NanoRacks ISS Launcher[6]

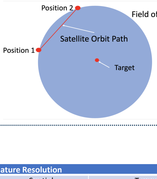
Orbital Modelling and Launch Options





The start time, stop time, and total duration in seconds of a CubeSat access times to College Station between May 16th and May 17th, 2020.

Start Time (UTC)	Stop Time (UTC)	Duration (s)
16 May 2020 02:24:28.108	16 May 2020 02:25:31.255	63.147
16 May 2020 10:33:28.336	16 May 2020 10:34:31.426	63.090



Sensor Options

Phenomenon	Parameter	Signature Resolution		
		Spectral (Region)	Spatial	Temporal
Automobiles and Airplanes	Length, Width, Height	Visible and Infrared Light bands	1-1.5 m	Single Sample
	Speed	Visible and Infrared Light bands	1-1.5 m	Multiple Samples
	Temperatures	Infrared Light bands	1-10 m	Single Sample
	Gas Emissions	Infrared Light (Reflectance) bands	10-30 m	Continuous Sampling
Facilities and Emergencies	Length, Width, Height	Visible and Infrared Light bands	10-30 m	Single Sample
	Temperatures	Infrared Light bands	10-30 m	Single Sample
	Gas Emissions	Infrared Light (Reflectance) bands	10-30 m	Continuous Sampling
	Aerosol Index	Ultra-Violet Light bands	10-30 m	Continuous Sampling
Construction and Mining	Length, Width, Height	Visible and Infrared Light bands	1-2 m	Single Sample
	Speed	Visible and Infrared Light bands	1-2 m	Multiple Samples
	Temperatures	Infrared Light bands	1-10 m	Single Sample
	Gas Emissions	Infrared Light (Reflectance) bands	10-30 m	Continuous Sampling
	Footprint	Visible and Infrared Light bands	10-30 m	Single Sample

Phenomena	Parameter	Sensor Type	CubeSat Heritage	CubeSat Heritage at Spatial Resolution	Future Sensor Development Needed?
Automobiles and Airplanes	Length, Width, Height	Panchromatic/ Multispectral	Yes	Yes	No
	Speed	Panchromatic/ Multispectral	Yes	Yes	No
	Temperatures	Multispectral	Yes	No	Yes
	Gas Emissions	Hyperspectral	Yes	No	Yes
Facilities and Infrastructural Emergencies	Length, Width, Height	Panchromatic/ Multispectral	Yes	Yes	No
	Temperatures	Multispectral	Yes	No	Yes
	Gas Emissions	Hyperspectral	Yes	No	Yes
	Aerosol Index	Multispectral	Yes	No	Yes
Construction and Mining Events	Length, Width, Height	Panchromatic/ Multispectral	Yes	Yes	No
	Speed	Panchromatic/ Multispectral	Yes	Yes	No
	Temperatures	Multispectral	Yes	No	Yes
	Gas Emissions	Hyperspectral	Yes	No	Yes
	Footprint	Panchromatic/ Multispectral	Yes	Yes	No

Conclusions

- Phenomena of Interest identified
- CubeSat architecture and system options identified
- Orbital capabilities and deployment methods developed
- Sensor options identified

Future Work

Immediate Work

- Develop surrogate data set of representative data
- Develop methodology for characterization on surrogate data set based on machine learning techniques
- Create illustrative application of the technology

Next 4 years

- Task 2: Specification development for a CubeSat-based global surveyor
- Task 3: Computational and experimental program based on surrogate and simulated data sets demonstrating capabilities of the orbital surveyor platform
- Task 4: CubeSat design and data analysis towards a future demonstration launch program

References

1) Automobiledimension.com, 2020. https://www.automobiledimension.com
2) Worledge, Rachel. “Free Flow Vehicle Speed Statistics: Great Britain 2012”. Vehicle Speeds Statistics, UK Department for Transport, 2013.
3) “Greenhouse Gas Emissions from a Typical Passenger Vehicle”. US Environmental Protection Agency, 2018. https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle
4) Bastan, Muhammet et al. “Remote Detection of Idling Cars Using Infrared Imaging and Deep Networks”. Nanyang Technological University, 2018.
5) Nieto-Peroy, C., & Emami, M. R. “CubeSat Mission: From Design to Operation”. *Applied Sciences*, *9* (2019) 3110. doi: 10.3390/app9153110
6) Wann, Alun. “NanoRacks CubeSat Deployer Clearance Cone Definition”. CAMMP AI EC-1375. 19 Aug 2013.