Monitoring Nuclear Facilities By Satellite Using Deep Learning Algorithms

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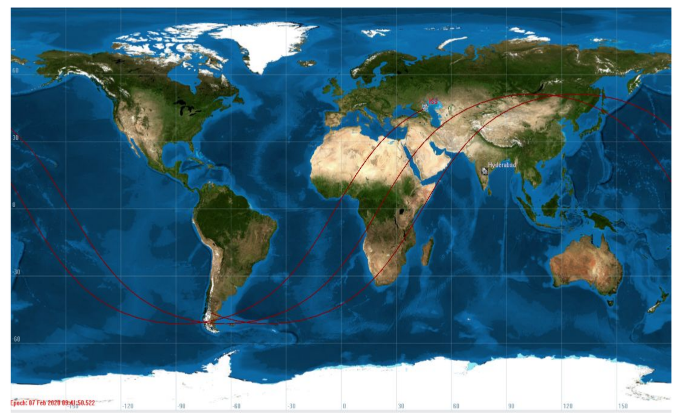
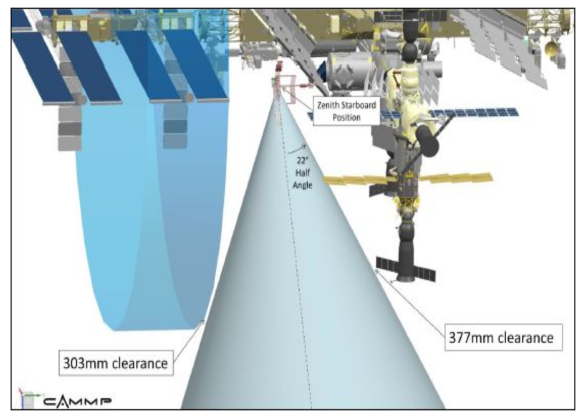
Introduction

- Cube satellites (CubeSats) provide a unique platform for monitoring of localized processes anywhere within the planet surface or atmosphere.
- Areas of interest can be targeted at certain times on an on-demand basis
- CubeSats equipped with adequate sensors and data analytics capabilities can create a characterization surveillance method
- Integrated program consisting of computational and experimental elements
- Lead to prototype design of a system to be launched from the International Space Station (ISS) and others using NanoRacks platforms





Project Objectives

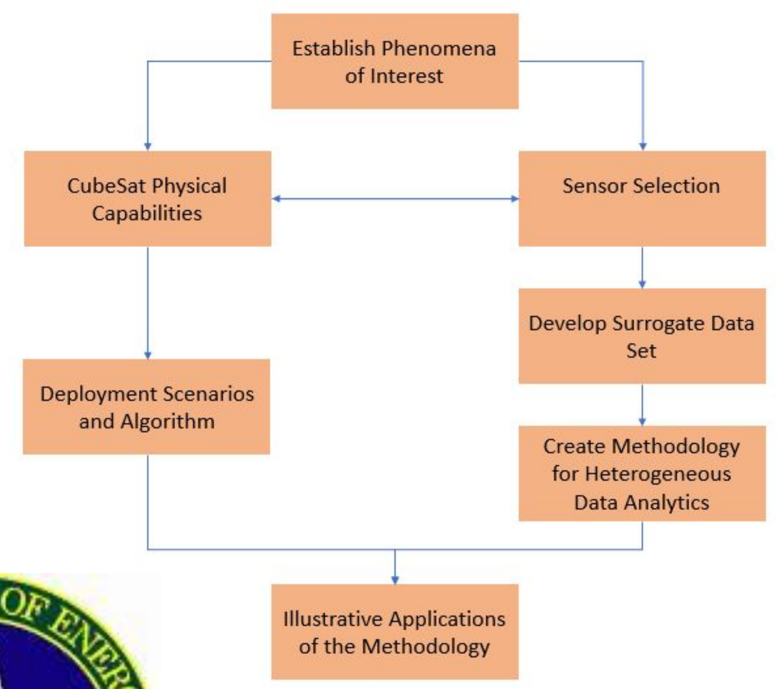
The effort is focused on science and technology of predictive and on-demand characterization of localized developments on the earth surface, subsurface and within atmosphere:

- 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 RGB available images to test and tune architecture
- Task 4. CubeSat design and data analysis towards a future demonstration launch program

Schedule:

Year 1: CubeSat-based global surveyor architecture development
Year 2: Specification development for a CubeSat-based global surveyor
Year 3: Computational and experimental program based on surrogate and simulated data sets demonstrating capabilities of the proposed orbital surveyor platform
Year 4: CubeSat design and data analysis towards a future demonstration launch program
Year 5: Continuation of all work

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

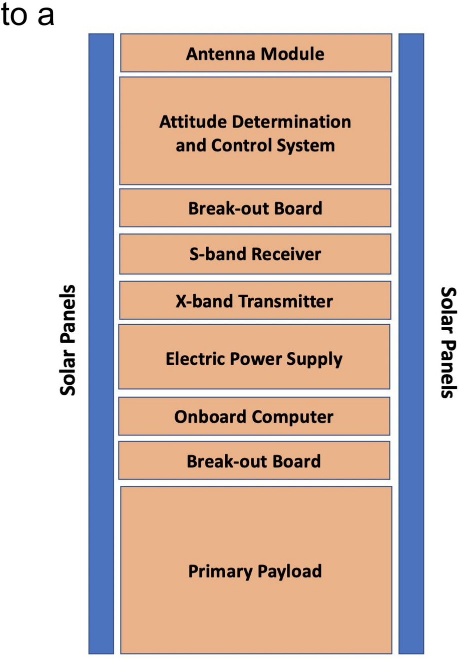
Signatures
- Dimensions
- Speeds
- Emissions
- Temperatures
- Other

CubeSat Platform Analysis

CubeSat Architecture
- CubeSats are measured in units of U, 1U is equal to a 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
- Altitude Control System
- Antennas
- Onboard Computer and Circuitry

COTS



Deep Learning Algorithms

Since data can be collected of existing nuclear facilities through most of the nuclear fuel cycle, Deep Learning is an attractive method of machine learning to use. This allows for an ability to recognize changes to known nuclear facilities, as well as detecting unknown nuclear facilities. By training in many available bands and sensors, changes can be identified outside of the visible range.
- Deep Learning Algorithms are commonly used to identify object in photos, and many have been done specifically through satellite images
- Through the use of Deep networks like ResNet-18 and other methods like the ones used in U-Net, high accuracies can be obtained on specific buildings and other objects to correctly identify phenomena of interest
- Through online sources, datasets can be obtained freely for this project, which make testing fairly simple.
- Many nuclear facilities have unique architectures that make them stand out from normal buildings. A human may be unable to precisely identify exactly what these features are, so creating a machine to recognize them may be ideal.
- Despite there not being thousands upon thousands of each recognizable case, data augmentation can be used to substitute the lack of data. By being able to multiply existing data several times, this makes the small number of facilities to train on not as big of a problem since the features can be kept while adding more trainable data.
- Limitations are that some cases may not be so easily obtained. Being able to use the same type of machine learning to recognize certain events require data of this case to train on. Fires and blackouts would be tough to find.

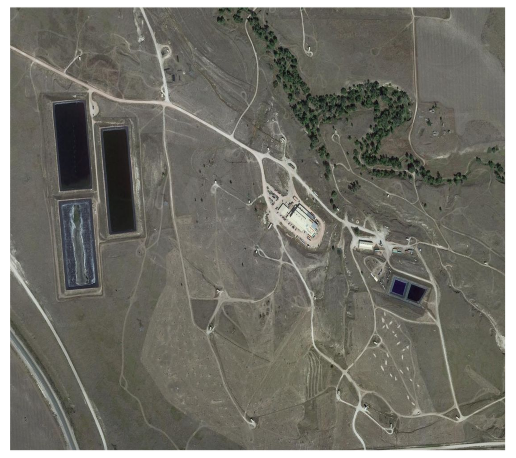
Testing Dataset

- Open Sourced Satellite Images
  - Lack of satellite images in all required bands
  - Giving the DL algorithm RGB images to prove concept
- Data augmentation to give more data and variation
- Four different sensor types and signatures
  - "Dimension": Panchromatic/Multispectral in VIS-NIR
  - "Temperature": Multispectral in IR
  - "Gas": Hyperspectral in IR
  - "Aerosol": Multispectral in UV
- Currently focusing on Dimension sensors
- Labels created for each image for presence/absence of a kind of phenomenon
- Looking into the entire Fuel cycle for nuclear materials to monitor all facilities

Enrichment

Nuclear Reactor

Mining & Milling

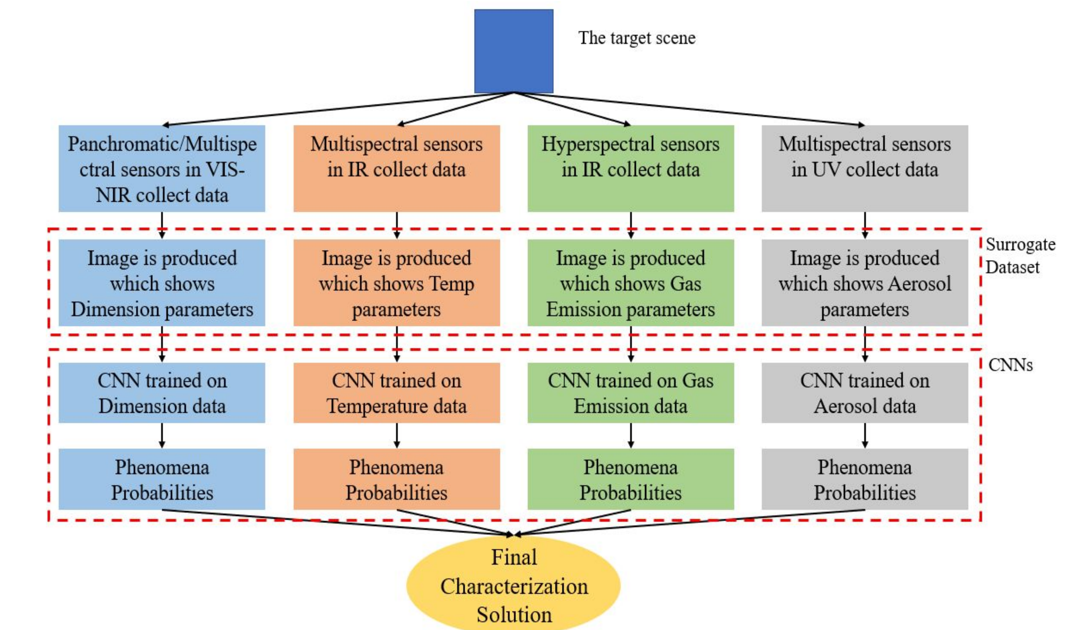


Dry Cask Storage

Conclusions

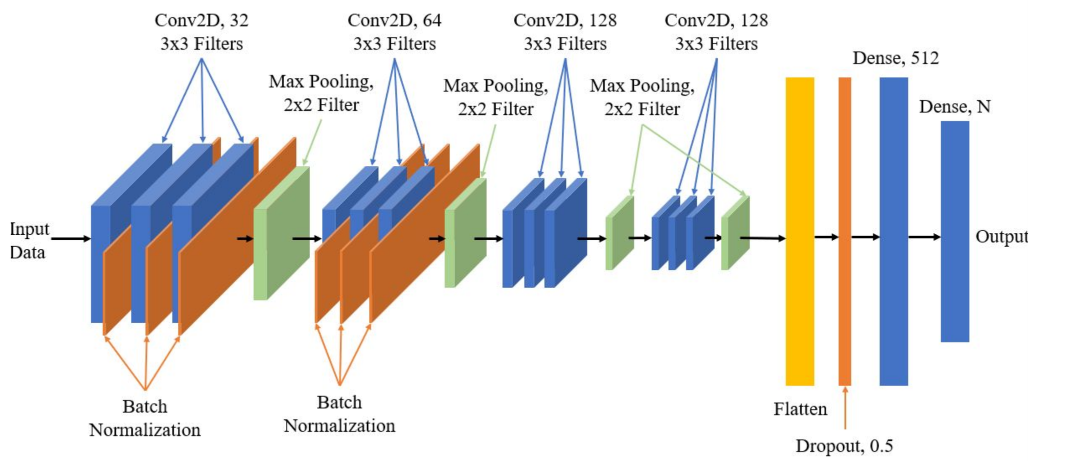
- **Developed foundation for phenomena and signatures of interest for surveillance**
- **Specification development and analysis of viable CubeSat architectures, systems, and sensors**
- **Computational methodology can be based on commonly used and proven architectures to work on real datasets**
- **Future Work**
  - Further phenomena and signature development and identification
  - CubeSat constellation development
  - Sensor development
  - Develop/adapt characterization methodology to other sensors

Characterization Methodology



$$P(phenomenon_i) = [P(phenomenon_i|D) + P(phenomenon_i|T) + P(phenomenon_i|G) + P(phenomenon_i|A)]/N_p$$

Example CNN Architecture



Significance

By creating a situation where nuclear facilities can be monitored from a distance and without having a person physically there, this can open up a lot of options for surveillance of these facilities. The most obvious one being a method for the International Atomic Energy Agency to monitor, or apply safeguards to states under it. States may enjoy the method being less intrusive, and may enjoy the ability to detect clandestine facilities to record if a state is using nuclear material for non peaceful purposes.

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