

Detection via Persistence: Leveraging Commercial Imagery from Small Satellites



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PRESENTED BY

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- Introduction
- Goal
- Image Acquisition and Preliminary Analysis
- Development, Training, and Validating Machine Learning Algorithms
- Future Work

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- Satellite imagery used in international nuclear safeguards to verify correctness and completeness of member states' declarations
 - Example: monitoring construction of nuclear facility as part of Design Information Verification (DIV)
 - Example: preparing International Atomic Energy Agency (IAEA) for inspections
- Satellite capabilities have traditionally evolved in two ways:
 - Increasing spatial resolution of images
 - Development and deployment of new sensor types (multispectral, hyperspectral, synthetic aperture radar, thermal)
- New trend is to take advantage of temporal aspect of monitoring
 - Multiple images of a site over short time window

- BlackSky is one company that will allow this capability
 - Provides platform/tool to acquire archived images (taken by partner satellites), task partner satellites, or task BlackSky satellites (currently 2 on-orbit with up to 60 expected)
 - Allows tasking to achieve rapid revisit rates of locations (up to 30 imaging opportunities/day) – this is what we mean by *persistence!*
 - High-resolution images (1-m or less)
- We are collaborating with BlackSky on this project to show utility of persistent imaging for international nuclear safeguards
- Three-year effort (currently in year-2)

- Demonstrate capability improvements of persistent imaging (rapid revisit rates, i.e. 30 images/day, over a site) for international nuclear safeguards
- What does this mean?
 - Understand and highlight what activities/processes/changes can be seen with more frequent imaging versus traditional satellite acquisitions (occurring no better than once a week typically)
 - Understand and highlight that image acquisitions at non-traditional imaging times (not just ~10:30 a.m. and ~1:30 p.m.) may provide value
- Two main elements of our project
 - Acquisition of multiple images per day over a site and analysis of those images to identify activities and objects of interest
 - Automated techniques to *assist* human analysts in detecting and labeling objects of interest in those images

- Skilled human analyst can:
 - Determine what visible observables are significant
 - Experiment, find, and verify the significant observables
- Human imagery analyst cannot find many of these observables AT SCALE
- And, with increased imagery there is increased burden on human analyst
 - Skilled analyst may only be able to search 100 – 250 square km per day
 - More detailed analysis including object labeling decreases search area per day
- A computer-based algorithm can take human identified observables and collate them at scale
- Algorithms won't replace human analysts but inform their processes and streamline their effort
- We will develop, train, validate, and test machine learning (ML) algorithms to inform human analysts

- During FY18 performed initial site monitoring and limited-scope data analytics
 - Site selection with activities of interest (i.e., construction)
 - Image acquisition (as many as possible in three-week window) using BlackSky's partner satellites
 - Human analyst object labeling (mostly vehicles as those were changing frequently)
 - Determined there was simply too much data for human analyst and began implementing ML algorithms to automatically label objects of interest

RAPID REVISIT RATE OF SITE

Six Commercial Image Burst of Site A “Industrial Site” in 25-hour (hand-labeled)

Change Detection: Six-Image Temporal Analysis of Vehicle Movement at Construction Support Facility: 28 May 2018 1114 (Local Time) – 29 May 2018 1352 (Local Time)



2018/05/21, 13:26:19 am (Local), 119 Detections



2018/05/21, 13:26:19 am (Local), 119 Detections



* CNN = Convolutional Neural Network

TRAINING DATA FOR ML ALGORITHMS

- Used our initial persistent monitoring demonstration and data analytics to refine our approach
- ML algorithms require significant amount of training data
- To increase our training data (especially while BlackSky is increasing their constellation), using other datasets
 - Functional Map of the World (fMoW) is test dataset collected from variety of commercial satellite systems as ML test data source. 63 different object classes have been labeled by users (nuclear power plant, construction site, tunnel entry) set in a variety of locations and environments
 - Cars Overhead with Context (COWC) second dataset to develop, train and validate ML algorithms. Contains 32,716 unique annotated cars in high-resolution overhead data.
 - xView contains 1 million instances of objects with 60 classes (grouped into classes like aircraft, vehicle, building, truck, ship). Differ from fMoW in that objects are smaller in size and labeling is more granular

CHARACTERIZING ML ALGORITHM PERFORMANCE

- Validate ML algorithms on fMoW/COWC/xView datasets with the following tasks:
 - Label experiment – how many labels are needed to get good performance on classification of dataset?
 - Terrain generalization – how well does a network trained for classification problems in one type of terrain generalize to areas of world with different types of ground cover?
 - Object detection – how well can a neural network detect and localize an object that varies in orientation, background, resolution and illumination?
 - Resolution – how does the resolution affect classification performance if the network is trained and tested on data with differing resolutions?
 - Pattern-of-life – what insights on patterns of life does the neural network object detector provide, and how do these insights help a human analyst? This task will analyze statistics from object detection over our selected site. A human analyst will interpret the statistics to determine what insights they provide.
- Test ML algorithms using BlackSky dataset as appropriate

- Concurrently to development, training, validation of ML algorithms, we continue to use BlackSky (archived, tasked) to acquire imagery over surrogate site
- Custom event feed
 - Creates channel based on interest and keywords
 - Open source news articles with these keywords collected in these channels
 - Can allow open source information to drive dynamic persistence where images automatically taken based on events unfolding on ground
- Imagery collected will be provided to human analyst for object labeling, and input into ML algorithms for object labeling

- We are demonstrating capability improvements of persistent imaging (rapid revisit rates, i.e. 30 images/day, over a site) for international nuclear safeguards
- We are acquiring multiple images per day over a surrogate site and analyzing those images to identify activities and objects of interest
- We are developing, training, validating, and testing automated techniques to *assist* human analysts in detecting and labeling objects of interest in those images