SPACE GROUND SENSORWEBS FOR VOLCANO MONITORING

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ABSTRACT

Increased space and ground sensing is enabling dramatic new measurements of a wide range of Earth Science and Applied Earth Science phenomena, including: volcanism, flooding, wildfires, weather, and many other phenomena.

New Space ventures have produced significantly greater access to data and miniaturization of sensing has enabled cubesats and smallsats to deliver data of outstanding resolution. The advent of the internet of things has produced incredible amounts of relevant terrestrial data as well.

Artificial Intelligence offers the potential to automate both data interpretation and resource allocation to best allocate sensing assets. We describe efforts to build and experiment with such "sensorweb" systems and offer some direction for the future sensorweb observation systems.

1 INTRODUCTION

Recent developments have produced an explosion of information sources relevant to environmental monitoring. Ground based sensors are being deployed at an incredible rate, and their data is more easily accessible via the Internet of Things (IoT). This explosion of networked sensors even extends to space, where traditional actors have deployed worldwide monitoring assets such as Terra and Aqua, Suomi-NPP, Sentinel, and Worldview and New Space actors have deployed assets such as Planet's Dove (with over 100 spacecraft), Skysat, and other constellations. Communications constellations such as SpaceX Starlink have received approval to launch over 12,000 satellites with plans for over 30,000 more [1]. Amazon Kuiper has competing plans of similar scale.

One challenge in this new era is how to combine all of these information sources to study complex spatiotemporal science phenomena, particularly when observing assets must be redirected in order to best collect data. When events can rapidly change 24/7 and diverse datasets must be incorporated in order to determine best future observations, traditional, labor intensive approaches do not scale well. In this use case, novel, Artificial Intelligence (AI) based methods offer the potential to enable scaling to large, diverse datasets and 24/7 rapid response operations.

We describe a new prototype sensorweb [2] which leverages recent commercial assets [3] in which many diverse inputs are constantly interpreted to track science activity. This continual interpretation is then used to automatically, dynamically direct observation assets to improve tracking and measurement of the target science phenomena. We demonstrate this concept to automatically observe volcanoes based on a number of alert systems.

The sensorweb concept [4] embodies continual 24/7 ingestion of new data from assets, constantly assimilating it into models that represent the systems current assessment of the phenomena under study. This assessment can trigger additional measurements, reconfiguration of sensors, data fetching, and/or processing of data and forwarding of data and/or alerts to end subscribed users (See Figure 1.).

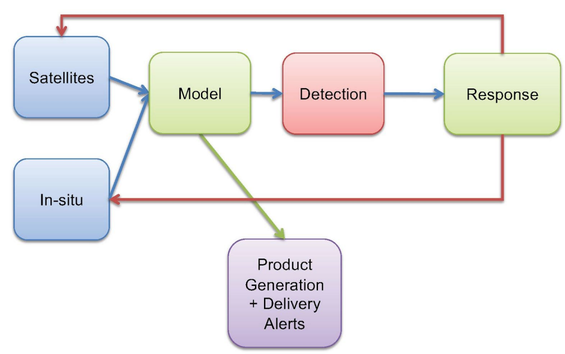

Figure 1. Sensorweb Concept

2 PRIOR SENSORWEBS UTILIZING EARTH OBSERVING ONE

A number of prior pilot sensorwebs leveraging automation for the Earth Observing One (EO-1) mission have been demonstrated.

2.1 Volcano Sensorweb

For over a dozen years (2004-2017) the EO-1 Volcano Sensorweb integrated alerts from scores of ground and space systems and used these to distribute alerts and also task the EO-1 spacecraft [5]. In this time period over 160,000 alerts were processed resulting in over 9000 volcanic scenes acquired of over 200 distinct volcanoes. This volcano sensorweb achieved a hit rate of over 35% of scenes with an active thermal detection compared to 2% for blind monitoring with MODIS.

2.2 Flood Sensorweb

EO-1 was also utilized for the 2010-2011 and 2011-2012 flood seasons in a MODIS triggered sensorweb [6] that achieved a doubling (e.g. 2x the number of scenes available) of high spatial resolution flood map products delivered to the Hydro Agro Informatics Institute of Thailand. EO-1 was also used to monitor flooding in Namibia [7] in a collaboration with hydrologists in Namibia.

2.3 Other Sensorwebs

EO-1 was also used to automatically monitor wildfires in Thailand using a FIRMS/MODIS triggered system [8]. Daniel Mandl and his team also had several collaborations with the USFS using EO-1 to support both wildfire response and Burn Area Emergency Response (BAER).

EO-1 was also used in cryospheric tracking in senssorweb demonstrations and also Marine Sensorweb [9] applications.

3 NEW OPPORTUNITIES

Many new space-based observation systems have been launched with additional systems launching every year.

Traditional general-purpose global coverage systems such as the MODIS instrument on Terra and Aqua and the VIIRS instrument on Suomi NPP and NOAA-20 provide excellent spotting capabilities. The European Space Agency's Sentinel series of missions offers a wide range of sensor modalities with extensive coverage of the globe. Sentinel provides C-band SAR, Multispectral, Thermal IR and atmospheric measurements at a global scale.

Precipitation relevant sensors on missions such as Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM) and many others offer new opportunities to track flooding [10].

For volcano study, new synthetic aperture radar offer the ability to measure inflation through interferometry and many new measurements of gas emissions and ash are now available to supplement thermal measurements.

Finally, new commercial space actors offer new avenues for earth observation, such as Planet Inc.'s network of 100+ Dove spacecraft [3] imaging the majority of the Earth's landmass every single day at 5m/pixel spatial resolution and additional assets provided targeted even higher spatial and spectral resolution (e.g. 21 Skysats at 0.71m/pixel spatial resolution). Blacksky Global plans a constellation of 20 satellites by the end of 2020 [11]. Satellogic has launched 5 satellites with hyperspectral capabilities with plans for expansion to 18 by the end of 2020 [11].

Likewise, in-situ instrumentation is growing dramatically. Sensors measuring temperature, weather, seismography, tilt, gas chemical composition, strain, water depth, water flow, and many others are now being deployed in a wide range of science applications. More importantly, advanced low power networking techniques are enabling such sensors to be rapidly, cheaply, and reliably networked into larger scale monitoring systems. An important area of this work is to enable node, subnetwork, and network level intelligence to appropriately interface with the remainder of the network providing low level sensor data streams to higher level alert data, managing and conserving resources in context [12].

4 CURRENT PROTOTYPING

We are currently developing an analysis and simulation framework in which we can evaluate different phenomenology tracking and tasking strategies relevant to the sensorweb concept. This is one piece of the larger effort by NASA's Earth Science Technology Office (ESTO) New Observing Systems (NOS) Testbed [13].

4.1 Scheduling Testbed

Our team has focused on the scheduling, resource allocation, coordination, and execution portion of the NOS concept. To support this effort, we have integrated overflight analysis software that enables us to calculate when satellites will overfly specific point targets, thereby enabling simulation of various tasking strategies and analysis of which events would have been imaged by a large range of actual and virtual assets. We have used this software to simulate numerous space-based observations, requiring only a two line element (TLE) or orbital kernel for an asset.

Using Celestrak [14] provided TLE information enables simulation of a wide range of assets. The overflight software produces roll angle, off nadir angle, emission angle, target solar zenith angle, and other geometric information to allow for the scheduling problem to incorporate various observation hard or soft constraints and slewing capabilities as desired. However we do not consider truly agile observations in which the overflight time is actually a range due to pitch forward/back during observation capabilities (e.g. [15, 16].

Finally, we are experimenting with a range of tasking (scheduling) strategies provided the inputs described. Thus far we have focused on dynamic programming techniques based on operational [17, 18] and proposed schedulers [19].

Our approaches are based on generating an initial schedule rapidly based on simplifying decomposition assumptions (such as scheduling each satellite independently, or greedy forward sweeping in time methods) and then incorporating feedback from schedule quality metrics to iteratively improve the solution.

We are also investigating several scheduling challenges:

· continuous planning, in which alerts come in continuously and the observation schedule must be updated (with preference for minimal schedule disruption) with sufficient lead time to respond to alerts;
· federated scheduling, in which requests can be made for a subset of assets not under direct control of the scheduler with limited information as to if the request will be fulfilled; and
· cloud cover nullification, in which observations fail with a coarsely estimable likelihood based on cloud cover.

The scheduling testbed allows us to experiment and evaluate these prototype methods on a wide range of problem types and quality metrics.

4.2 ESTO NOS Testbed

The Earth Science Technology Office New Observing Systems Testbed is bringing together technologists and scientists to integrate disparate modules to demonstrate new observation paradigms [13]. As part of this effort the scheduling algorithms developed above will be tested within an integrated NOS with simulated and actual assets to highlight the potential of such systems to revolutionize Earth Science.

4.3 Volcano Sensorweb

Also as part of this effort, we are prototyping a volcano observation sensorweb to serve as a driving use case for senworweb technology development. In this effort we have operationalized tracking of a number of volcano monitoring sources. Table 1 shows the volcano monitoring sources integrated into our environment.

Satellite triggers	**Trigger Type**	**Spatial Coverage**	**Temporal coverage**
MODVOLC (MODIS, Terra+Aqua)	Thermal emission	Worldwide	24/7
VIIRS Active Fires	Thermal emission	Worldwide	24/7
In-situ			
Iceland Met Office	Seismic	Iceland	24/7
IGEPN (Ecuador)	Reported	Ecuador	?
Serganomin (Chile)	Reported	Chile	?
USGS	Seismic	Worldwide	24/7
Other			
Volcanic Ash Advisory (VAAC)	Reported Aviation Ash	Worldwide: 7 regions integrated	24/7

Table 1: Volcano Monitoring Sources in current prototype.

In addition, we are collaborating with multiple flood monitoring teams targeting integrating flood monitoring triggers with both space-based and in-situ sensors.

In the Spring of 2020, we tested the above concepts in an end to end demonstration. Using the above triggers, we enabled automated tasking of the Planet Skysat constellation from a JPL sensorweb node. Three scenes were acquired as indicated below – triggered 11 February 2020 and acquisition on 13 or 14 February 2020.

Acquisition Date	Acquiring Asset	Target	Trigger
13 February 2020	Planet Skysat	Billy Mitchell (Papua – New Guinea)	VIIRS volc
14 February 2020	Planet Skysat	Nishinoshima	VIIRS Volc, MODVOLC
14 February 2020	Planet Skysat	Mere Lava	USGS Seismographic

Table 2: End to end demonstration acquired scenes.

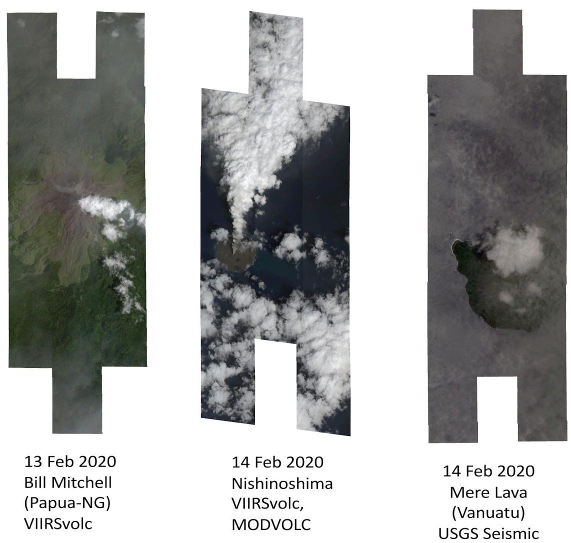

Figure 2: Acquired scenes from end to end demonstration of 11-14 February 2020.

In this demonstration, only overflight/target is checked at JPL with almost all of the deconfliction happening within the Planet scheduling system. However in the general system the architecture is designed to support a federated scheduling system where local many loose coordinated entities manage their own internal resource allocations.

We are currently working to expand the sensorweb to include additional taskable assets such as the ECOSTRESS instrument currently onboard the ISS as well as other relevant commercial assets such as the Planet Dove constellation. We are also working to integrate automated analysis of the volcanic thermal signatures from satellite sources (e.g. Skysat, Dove, ECOSTRESS).

4 RELATED WORK

For a review of prior sensorweb work applied to volcano monitoring see [5]. For a summary of prior work in integrating space based measurements of flooding see [20, 6].

5 CONCLUSIONS

We have described ongoing efforts to link together space and ground assets in a “sensorweb” to enable rapid direction and allocation of assets to monitor, observe, and study fast moving science phenomena such as volcanic activity, flooding, wildfires, and marine events such as algal blooms. We have described several elements of the overall sensorweb concept and highlighted some preliminary demonstrations using Planet Skysat.

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