Automated Scheduling of Federated Observations in the NOS Testbed

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Abstract

The advancement of remote and in-situ sensing technology, combined with the emergence of New Space ventures, is producing a variety of new measurements for Earth Science phenomena. New observation techniques must combine and leverage these federated systems. In developing this new paradigm, NASA's Earth Science Technology Office is developing the New Observing Strategies (NOS) Testbed to validate and demonstrate new operations concepts. As a part of this effort, we have developed a planning and scheduling system to support automated retasking

Introduction

Advances in sensor technology and the arrival of new remote sensing actors such as Planet, Worldview, and Capella, has produced an explosion of new information sources for earth observation. It is challenging to combine these new information sources to study complex science phenomena. This information must then be used to identify and request additional observations. Sensorwebs can constantly interpret diverse inputs to automatically direct assets to improve tracking and measurement of target phenomena.

Networks of remote and in-situ sensors can be combined into sensorwebs to more accurately depict environmental phenomena. These science models can identify or project events of interest, such as flooding or a volcano eruption, which can be used to trigger additional observations by target-able and adaptive sensors. As part of this effort, we developed the planning node for NOS – a scheduling system to support a federated scheduling problem, creating schedules for spacecraft controlled by other organizations, requesting observations from external assets based on this schedule. Any generated data products can be then fed back into the model, improving future utility estimates.

Scheduling Testbed Technologies

The planning node consists of an overflight calculator and a scheduler. The overflight calculator determines when satellites will be able to observe desired targets, and the scheduler requests observations based on observability and other constraints. These elements were previously demonstrated to observe volcanic activity.

Overflight calculator

We have developed overflight analysis software that enables us to calculate when satellites will overfly specific point targets. This creates many potential candidate observations. To generate them, we use a two line element (TLE) or orbital kernel for a real or theoretical asset. The overflight software produces roll angle, off nadir angle, emission angle, target solar zenith angle, and other geometric information. This can be incorporated into the scheduler for use in constraints and slewing capabilities. We do not consider truly agile observations in which the overflight time is actually a range due to pitch forward/back during observation (Chien et al. 2020a).

Scheduler

Dynamically retasking satellites in response to continuously triggered alerts is challenging because updated observation priorities must be communicated to the satellites, and the observations of one satellite can influence the observation priorities of another. Imaging must be done in the context of finding a feasible up-/down-link schedule and is subject to orbital constraints. Our approach is to treat constituent scheduling problems, e.g., the imaging of a single satellite, as loosely-coupled subproblems, solving them independently but employing various heuristics for communicating how the solution to one subproblem might influence the others. Full details on the scheduler will be published in a separate paper.

Our current approach for federated scheduling is to first schedule with all candidate satellites. After scheduling, for each satellite we submit that satellite's scheduled observations as requests to the organization that operates the satellite.

Data Processing

Automatic data product generation may be required as part of the planning node. Processed data can be used for automatic ingestion by a science model, or delivered directly to subscribed scientists.

The exact processing depends on the type of tasked assets and the phenomena we are observing. Therefore, it must be implemented on a case by case basis. One use case is flooding. We implemented a process that automatically calculates surface water extent from Planet imagery, based on (Cooley

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et al. 2017). We calculate the NDWI for each image pixel. Using dynamic thresholding we classify them as land, water, cloud, or missing.

Volcano Sensorweb Demonstration

We have previously demonstrated the overflight calculator and scheduler for a volcano observation sensorweb. This Volcano Sensorweb serves as a driving use case for sensorweb technology development. In this effort we have operationalized tracking of a number of volcano monitoring sources, such as MODVOLC, VIIRS Active Fire product, VAAC, and the Iceland Met Office.

In Spring 2020, we tested the above concepts in an end to end demonstration. Using the given triggers, we enabled automated tasking of the Planet Skysat constellation from a JPL sensorweb node. Three scenes were acquired in early February (Chien et al. 2020a).

ESTO NOS Testbed Integration and Demo

We have integrated our scheduling and tasking system into a prototype of the ESTO NOS Testbed. The testbed is composed of several separate modules, including a flood model, an in-situ stream gauge node, and a real time VIIRS receiver. The nodes communicate through a publish/subscriber messaging system. The planner node primarily interacts with the flood model node. The planner can be started by any node that has produced triggers of earth science phenomena. In the future this can be a collection of several nodes modelling various phenomena.

The current Testbed is focused on a hydrology use case, observing cases of flooding. The hydrology model predicts flooding based on an aggregate of data sources. This system supplies alerts describing the location, time, and significance of a flood event.

We take these alerts and feed them into the previously described overflight calculator. We use TLEs from Celestrak and propogate them to the correct time (Celestrak 2020). We plan for several satellites, including Planet Skysat, Worldview, ISS, Capella, and Spire satellites, consisting of 28 total taskable assets. This list can be modified as needed. To make the problem more realistic, we also give the scheduler a set of contending targets. These targets consist of a set of volcanoes, and random target points around the Earth's landmass. There is typically around 3000 contending targets for an 8 hour timespan, though the exact amount varies.

After going through the overflight calculator, the overflight data is input into the previously described scheduler. The scheduler assumes you can take only one image at a time of a single target, and that it takes time to slew between targets. The time between targets is calculated as a linear function of angular distance.

We then take the schedule and send observation requests to the relevant organizations. Currently we are only integrated with Planet, but plan to integrate with Capella and others in the future. In Planet's case, the output of the schedule is parsed to find the Planet Skysat observations. We take these observations, and send them as a request to Planet. When doing a historical demonstration, this is simulated.

We completed a historical simulation focused on the March 2019 flooding event in the midwester United States. In the historical case, it is impossible to make requests for past observations. Skysat observations are simulated with historical observations from Planet's Dove constellation. While the imagery has different qualities, the Dove constellation images most of the Earth's surface every day (Planet 2021) so it is likely they have relevant imagery.

For each Skysat request we sent to Planet, we simulate the results by querying Planet's API to see if they have Dove imagery at that time and location. If they have the data, we combine adjacent or overlapping images. We grid the data into squares that align with the flood model. For each grid, we calculate the surface water extent by calculating NDWI and using dynamic thresholding (Cooley et al. 2017). The pixels are classified as land, water, clouds, or missing.

To complete the cycle, we downscale the surface water extent to the grid and send the information to the flood model node. The model node then assimilates the data, improving the quality of future requests.

Related Work

For a summary of prior work in integrating space based measurements of flooding see (Chien et al. 2019). We have previously applied a model driven sensorweb concept to hurricanes (Tavallali et al. 2020) and volcanoes (Chien et al. 2020b).

Conclusion

We have described a planning/scheduling node for use in NASA's New Observing Strategies (NOS) Testbed to evaluate different phenomenology tracking and tasking strategies relevant to the sensorweb concept.

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