Technology innovations over the past decade have driven substantial improvements in maritime situational awareness. We have come a long way from the early days when, as the world prepared for its second Great War, large ground-based radars were deployed on coastlines to detect aggressors approaching by sea and air. It is now possible to track assets and monitor threats world wide, from the comfort of your desk. The more important innovations are based on satellite technology and include high-resolution electro-optical and radar sensors, automatic identification system transponders, and communications systems relaying critical information in real time.

In recent years, innovations around situational awareness have accelerated, thanks in part to the emerging commercial space industry. Companies such as SpaceX, Google, and Planet Labs are driving the NewSpace movement – innovative space ventures that are developing faster and cheaper technology alternatives to deliver terrestrial data collected from space, compared to those traditionally funded by governments and larger aerospace companies. Those faster, cheaper technologies have birthed constellations of very small satellites (called, variously, cubesats, nanosats, or smallsats) that have development timelines of months rather than years or decades. For example, Silicon Valley-based Planet Labs currently operates a constellation of over 120 Doves (30x10x10 cm cubesats) that can map the entire Earth in a single day with three-metre resolution imagery (Figure 1). Spire, also based in Silicon Valley, operates a fleet of 80 cubesats with automatic identification system (AIS) receivers that capture the AIS signatures of ships at sea to provide global tracking of vessels.

These constellations have resulted in a data explosion: According to Planet Labs, its Dove constellation, for example, collects six terabytes of data each day, comprising some 1.2 million individual 29 megapixel snapshots or scenes. Given this data volume, it is simply not cost effective to use traditional analysis techniques (eyeballs on the image); rather, automation enhanced by deep learning techniques allow

Ocean Surveillance in the Age of the NewSpace

by Desmond Power

each pixel and target to be analyzed and repackaged in an easy-to-digest format.

The Planet and Spire examples show the effect that the NewSpace has had on ocean surveillance capabilities. In both of these examples, information from the constellations can be delivered to your desktop or, more conveniently, to your cloud service in real time for further analysis. From Planet, this could include ship detections and associated analytics from the Doves' electro-opical sensors. From Spire, this could include vessel information gleaned from its constellation's collection of AIS messages. Together, these constellations could provide additional detail, such as vessels that have their AIS transponders deactivated or are intentionally reporting incorrect information ("spoofing"). The information overload inherent in this massive dataset can be reduced by automation and artificial intelligence (AI), converting it to extremely useful information, providing a level of situational awareness several orders of magnitude higher than was available only a few years previous.

Myriad data analytics applications come to mind for ocean surveillance. One particularly important application for the North Atlantic is iceberg surveillance. Icebergs have been a threat to navigation in the North Atlantic since vessels first traversed its frigid waters (Figure 2). Since the early twentieth century, the International Ice Patrol (founded in response to public outcry in the aftermath of the *Titanic* disaster) has been providing ice surveillance information from fixed-wing aircraft to address this shipping hazard. Fixed-wing surveillance remains valuable, but in the NewSpace era it is supplemented with satellite-derived information.

C-CORE has been investigating how to extract iceberg information from satellite imagery since 1996 and the launch of Canada's RADARSAT-1 synthetic aperture radar mission. Throughout its 17-year lifespan, RADARSAT-1 provided valuable maritime domain awareness information on vessels, icebergs, and sea ice. However, the technology has advanced by leaps and

Figure 1: Planet Labs operates a constellation of over 120 Doves (30x10x10 cm cubesats) that can map the entire Earth in a single day. One Dove cubesat is pictured here with Desmond Power (left) of C-CORE and Sam Leiff of Planet Labs.

Figure 2: The International Ice Patrol provides ice surveillance information from fixed-wing aircraft to address shipping hazards. In the NewSpace era, aerial iceberg surveillance is supplemented with satellite-derived information.

bounds; we have the capability to image all Canadian waters every single day with the newly launched (July 2019) RADARSAT Constellation Mission (RCM). While not technically a NewSpace satellite constellation, RCM shares many revolutionary NewSpace characteristics: it is a smaller, cheaper version of its predecessors, yet provides vastly more data than can be practicably used by traditional means. Like its two predecessors, RADARSAT-1 and RADARSAT-2, RCM can enable surveillance of icebergs and vessels. The revisit (frequency with which it can return to and image the same area) of this constellation also enables new applications – which C-CORE is investigating – including monitoring the progression of icebergs from their source in the Arctic to their eventual break-up and melt. While detecting and tracking of many thousands of icebergs is now technically possible, we cannot feasibly put eyeballs on each image. However, in the age of cloud computing, AI, and deep learning, this application is well within the reach of innovation (Figure 3).

C-CORE's first experience of the application of deep learning in iceberg surveillance began a few years back with a machine learning competition that was co-sponsored with an international oil and gas firm. C-CORE scientists and engineers have been applying "computer vision" and machine learning techniques to improve iceberg surveillance for decades. However, we became intrigued by the potential for rapid improvement offered by deep learning and crowd-sourcing from the global big data community. In 2017 we approached Kaggle, a company that conducts online deep learning competitions among the million-person community of data scientists and machine learners. C-CORE proposed a simple binary machine learning problem: create an algorithm that can distinguish between vessel and iceberg targets in radar imagery. This is one step in a multi-stage process to detect, identify, and differentiate targets in satellite imagery. C-CORE provided a dataset of 5,000 ship and iceberg targets extracted from satellite-radar imagery, as well as a set 5,000 known ship and iceberg

Figure 3: There is now a capability to image all Canadian waters every single day with the newly launched RADARSAT Constellation Mission – a smaller, cheaper version of its predecessors that provides vastly more data.

detections on which competitors could train their algorithms. Over a three-month period, more than 3,300 teams from 93 countries worked the problem, incentivized by a $25,000 prize purse provided by Equinor. The competition produced a better classifier compared to standard computer vision techniques; the top three competitors had four to five stage classifiers that increased classification accuracy by approximately 5%.

Now that we know AI can improve one step of iceberg tracking, C-CORE can move on to automate other steps and link them together as we are doing with the "ship detection plus AIS" application. But let's not stop there. Imagine the possibilities with RCM's daily (sometimes twice daily) high-resolution coverage of the entire Arctic: suddenly, we can track individual icebergs as they are calved from each glacier. We develop algorithms using AI to mine the satellite imagery, identifying each individual berg and tracking its signature in subsequent images. This tracking can also be validated by AI-driven drift forecasting algorithms. And from all of this automation comes a big-picture analysis of iceberg flux, and the trajectory and fate of each iceberg.

All of this can be accomplished with a single satellite constellation – RCM. Now imagine the enhanced situational awareness information that can be gleaned from incorporating other NewSpace constellations. Spire and Planet will enable better vessel identification, allowing AI algorithms to remove false alarms from vessel targets. Furthermore, daily iceberg deterioration can be observed from multiple satellite scenes, providing critical information to meteorologists and climate scientists.

Private and public NewSpace constellations herald a new era in maritime situational awareness. Faster, cheaper, better innovations have led to an explosion of geo-information that can only be harnessed effectively with automation. Such automation will transition human involvement from simple naked-eye analysis to high-value data and computer science. Innovative technologies have increased the amount of information we have access to; we must continue to innovate to convert data into usable information and actionable insights for the benefit of humanity.

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