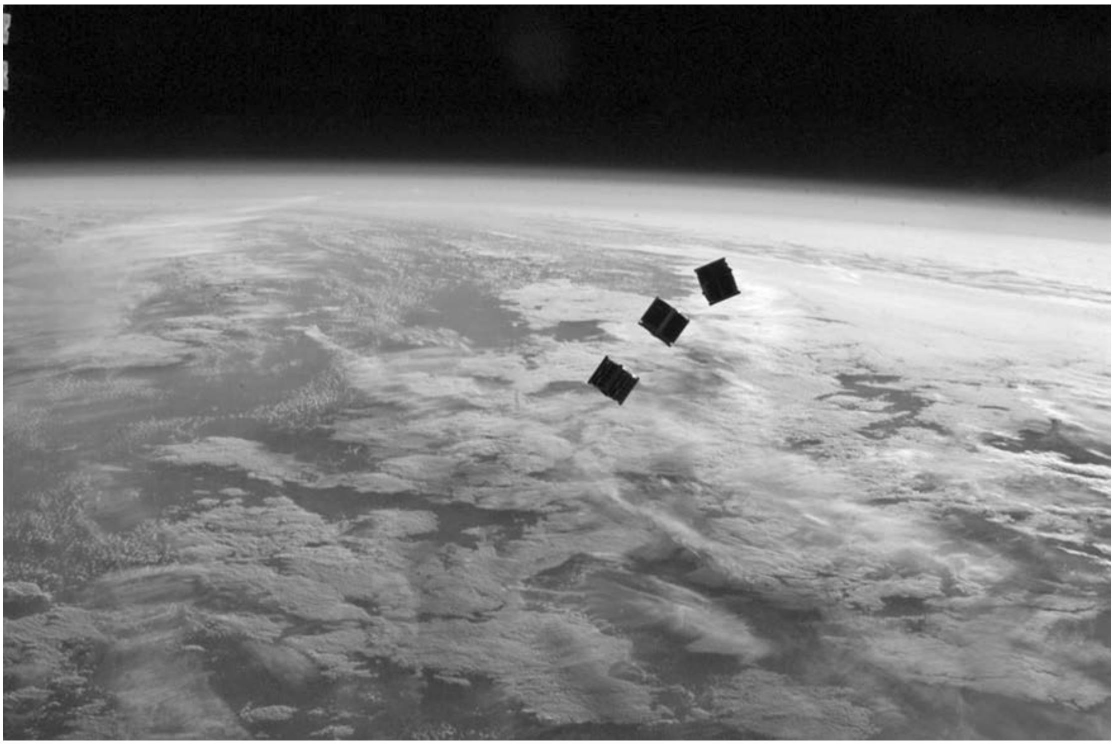
A Shot in the Dark

Shedding Light on Exoatmospheric Situational Awareness with Alternate Sensor Utilization

Dr. Jeremy L. Barnes, PMP
Ashley N. Elledge
Col Scott G. Patton, USAF, Retired



It's not rocket science—it's harder. Missile defense is not simply a matter of intercepting a bullet with another bullet. The relative speed of the small reentry vehicle (RV) is faster than that of a bullet by an order of magnitude. Furthermore, you're often firing in the dark into a lot of clutter. However, hitting an RV is not only possible but also has become the expected outcome of rigorous testing. One area for improvement is acquiring rapid and accurate situational awareness in time to find and destroy the RV. That's where CubeSats, or small satellites, equipped with advanced sensors may shed some light on the darkness.

Introduction to Missile Defense

The ballistic missile defense system (BMDS) is an integrated architecture of land, sea, air, and space assets designed to defend the United States, deployed forces, allies, and friends against all ranges of enemy ballistic missiles in all phases of flight (boost/ascent, midcourse, and terminal). The missile defense architecture provides a defensive operations capability around the clock. The strategy of the Missile Defense Agency (MDA) is to establish a capability-based acquisition approach to field initial elements and then build upon this foundation as new technology matures. Although the currently fielded system provides effective defense for the United States against the defined ballistic missile threat, the weapon system continues development and testing to meet evolving threats. Moreover, just as the need for improved space situational awareness has long been well justified, so does a need exist to continuously improve RV discrimination capabilities for missile defense.[1] Some solutions may help in both mission areas to better defend our critical space assets and our nation.

Areas for Improvement

Even with the myriad sensors available to the Department of Defense (DOD), an area for system improvement remains fully effective battlespace situational awareness. One of many efforts under consideration to better support the missile defense war fighter is further research on target-signature exploitation and multistatic CubeSat technology. The goal involves investigating the viability of utilizing a CubeSat platform equipped with specialized payloads to determine technical feasibility of low-cost sensing for target-signature exploitation. The applicability and practicability of hyperspectral and multistatic systems, as well as data collection through CubeSat constellations, all have potential. As demonstrated through real-world events, timely missile detection, together with the typing and resolving of objects, is crucial for establishing useful tracks for the possible cueing of ground-based sensors. The challenge resides in target-signature exploitation, which is currently limited by technological capabilities and sensor availability for collection opportunities, and in the associated high cost for supporting overhead sensors.

CubeSats could support other needs of war fighters, such as time-sensitive sensor fusion, by increasing the capabilities of much-needed space situational awareness. CubeSats are just one of many solutions, whether pre-positioned in orbit or ride sharing on missile defense interceptors. Hosted payloads, redesigned command and control, and communications platforms have merit as well. Potentially, with cooperation among the DOD's combatant commands and services, MDA, and national agencies, joint system development and coordination could field solutions to support improved space situational awareness, space protection, and missile defense capabilities.

As space-based sensing for military applications continues to grow as an integral part of advanced warfare, methods of overhead target-signature exploitation will advance and mature. Given the emergence of CubeSats, the utilization of low-cost sensing technologies with increased overhead coverage is becoming more evident and practical for military applications to support war-fighting operations and defense of the homeland. CubeSats might never fully replace larger space systems, but they could provide some utility to augment those systems with vital information, as have other unattended sensors in past ground conflicts.[2]

Consider the following improvements in the works. The BMD Overhead Persistent Infrared (OPIR) Architecture (BOA) processes data from multiple overhead sensors to detect, track, and resolve ballistic missile threats. The BOA's operational objective is to become an integral sensor-fusion-based contributor to the overall BMDS. The challenge in detecting missiles, resolving objects, conducting missile typing, and other phenomenology remains in target-signature exploitation.

CubeSat payload technology is improving rapidly and has the potential to support such exploitation. For low-cost solutions, the payload element faces numerous issues, including size, weight, and power (SWaP or SWaP-C with cost). Additional limitations to overcome include management of the required coverage, mechanisms controlling satellite separation, scalability for multistatics and hyperspectral sensing, and the necessary constellation size. Initially, CubeSat's target-object observations and data would likely be relayed immediately to a ground station for processing and subsequent tasking of other assets. Initial target detection (e.g., using OPIR) can inform a CubeSat constellation to prepare for object tracking and signature exploitation. Doing so calls for effective decision processing and communication, which are available with existing technology. CubeSats may yield a low-cost mechanism to position specific sensor technologies where and when they are needed, and they may increase the probability of obtaining data vital to supporting various military applications across the DOD.

Both government and industry are making a significant effort to explore improvements in CubeSat technology, including evaluation of various payloads, platforms, and constellation sizes. Theoretical research is under way to identify, evaluate, and establish physics-based models. Experiments are testing theoretical models through appropriate simulation methods to establish confidence in research viability and to better define and measure the validity of payload selection. Finally, prototypes are demonstrating proofs of concepts, and some operational systems are already employed.

Because such research will benefit many users, we need a collaborative effort utilizing a diverse group of researchers and operators from throughout the community to demonstrate any differentiated value in this emerging growth area. Target-signature detection and exploitation through the use of CubeSat or other hosted payload technology will offer a direct benefit to various sponsors, including the MDA, military, and other national agencies. A twofold benefit emerges through demonstration of low-cost space-based sensing to observe specific phenomena regarding target-object signatures as well as the additional capability to allow BOA to supply high-quality precision cues to ground-based sensors. Improvements can also assist the MDA's ongoing efforts to provide better postintercept assessment. The use of CubeSat constellations positioned for the right coverage at the right time through novel methods and miniaturization of specific payload-sensing technology can produce these effects.

CubeSats might integrate and rely on the cueing of larger space platforms on the one hand and might even augment the more capable systems on the other. The Pentagon plans to allocate billions of dollars to new initiatives over the next five years, including putting into orbit surveillance sensors that will expand commanders' awareness of space activity. Space situational awareness has been growing in importance and can greatly enhance the MDA's highest-priority mission to defend the homeland and forces assigned around the world from ballistic missile attack.

The Need for Change

As technology rapidly evolves, traditional large-scale legacy military system design and associated system engineering approaches must evolve as well. Developing effective, resilient, and affordable systems that meet the system's stated mission in a timely manner can be demanding.[3] This environment often drives incremental change and the use of common form, fit, and function commercial-off-the-shelf (COTS) components architected into military applications. The latest Department of Defense Instruction 5000.02, *Operation of the Defense Acquisition System*, 7 January 2015, which supports incremental advances in missile defense and space systems, reflects the design concept. Where feasible, taking advantage of common small-form-factor plug-and-play COTS products allows for a reduction in design cost and provides an avenue to insert technology advancements into military applications at an increased pace.

Our nation's space community embodies the same concept. According to the National Geospatial-Intelligence Agency, its success will depend on how it embraces change, especially that which is enabled by advances in technology in support of global coverage—one of the agency's stated mission areas.[4] On 24 April 2013, Gen William L. Shelton, commander of Air Force Space Command at that time, gave the following statement to the Senate Armed Services Committee:

> Our satellites provide a strategic advantage for the U.S., and as such, we must consider the vulnerabilities and resilience of our constellations. [We] are examining disaggregated concepts and evaluating options associated with separating tactical and strategic capability in the missile warning and protected communications mission areas. We are also evaluating constructs to utilize hosted payload and commercial services, as well as methods to on-ramp essential technology improvements to our existing architectures. Beyond the necessity of finding efficiencies and cost savings, we may very well find that disaggregated or dispersed constellations of satellites will yield greater survivability, robustness and resilience in light of environmental and adversarial threats.[5]

The preceding arguments support incremental development cycles, use of COTS technology, rapid technology insertion, and dispersed space-based constellations. A need exists to further examine target-signature exploitation through hyperspectral sensing and multistatics and to concentrate on miniaturization of these sensing technologies. The resulting systems might be hosted on small, space-based platforms to give the BMDS increased and persistent coverage.

Current Technological Direction

Sensing and Space-Based Platforms

Target-signature measurement, intelligence, and exploitation are critical for military applications and maintenance of a competitive advantage over our adversaries. Obtaining intelligence data on targets allows the detection, tracking, and identification of distinctive characteristics of fixed or dynamic target sources. These data include material, acoustic, and nuclear as well as chemical and biological intelligence. Traditionally with the BMDS, obtaining data has occurred primarily through the use of radar technologies combined with specific, large, space-based sensor assets that have many competing priorities. The purpose within the BMDS for collecting these data is for surveillance, target detection, target tracking, typing, discrimination, and postintercept assessments. The BMDS application may have its specific needs, but these collections inform many military applications.

To assist with space-based data collection and priority management, the MDA and its Space Knowledge Center made strides with the space community to define a planning infrastructure for preplanned and cue-related BMDS tasking. This approach offers a structure for the MDA to request and plan for data-collection events.

CubeSats are becoming a research and technology-development platform that can capitalize on the latest technologies and innovative micro/nanomanufacturing techniques.[6] As space-based sensing for military applications emerges and becomes an integral part of advanced warfare, overhead target-signature exploitation methods will continue to advance and mature. Now, with the emerging technological advance of CubeSats, the use of low-cost sensing technologies with the possibility for increased overhead coverage is becoming more practical for military applications.[7] The future will likely see more small satellites dedicated to a particular mission objective.[8]

Overview of Hyperspectral Sensing

Within the last decade, the demand for remote sensing data to examine and understand the composition of the earth's surface has significantly increased. Applications that rely on these data include agricultural studies, coastal research, marine analysis, geology, climatology, and the defense industry. Hyperspectral imaging addresses the needs of users of remote sensing data by combining spatial imaging systems with spectroscopy. Hyperspectral imagers supply a digital image in which each pixel consists of a spectral signature.[9] Ensuing images, along with the underlying spectral components, can identify Earth surface types (fig. 1).[10]

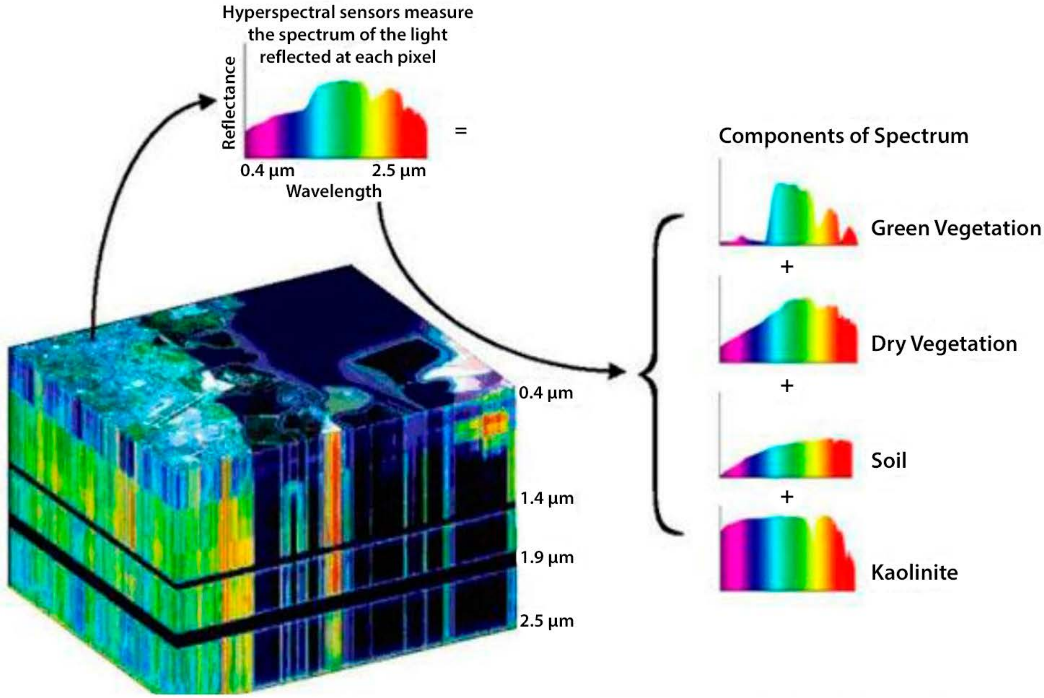


Figure 1. Hyperspectral imaging. Courtesy NEMO Project Office, United States Navy

One defense-related application of hyperspectral imaging is target detection and discrimination (i.e., determining which pixels in a particular image are likely to contain known target materials).[11] Research continues to leverage existing target detection, discrimination concepts, and algorithms and to investigate their incorporation into the BMDS via CubeSats.

Overview of Multistatics

Multistatic operation refers to a network of sensors that includes more than a single transmitter or receiver. Such operations build upon monostatic (colocated transmitter/receiver) and bistatic (spatially separated transmitter/receiver) concepts and can address the limitations of a sensor system's ability to detect and track objects of interest. Figure 2 depicts a multistatic radar scenario.[12] As shown in this illustration, each node in a multistatic sensor network can perform one of three functions—transmitter, receiver, or transmitter/receiver—to carry out the mission while the comprehensive system can be designed to maximize performance against specific or wide-ranging scenarios.[13]

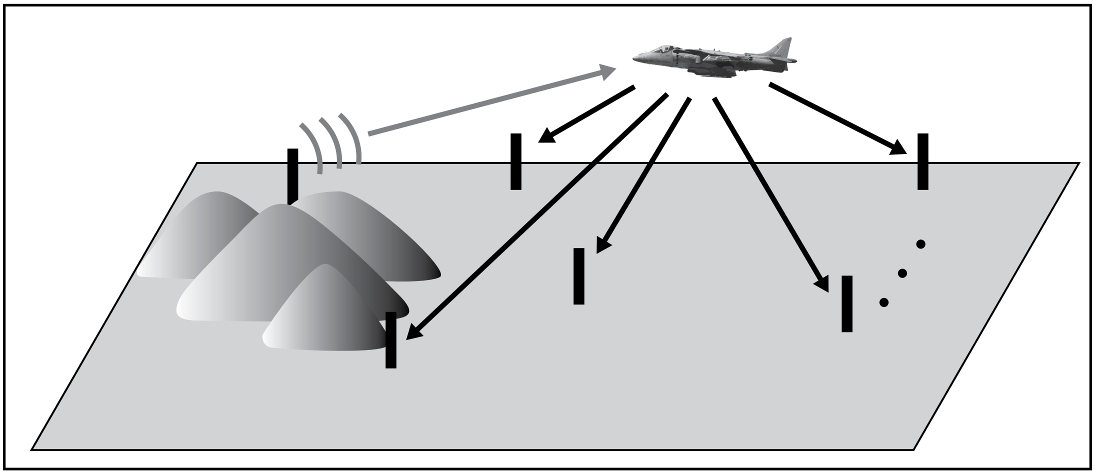


Figure 2. Multistatic radar vignette. (Reprinted from "Communication-Radar Signal Processing Sys.," Microwave and Fiber Optics Laboratory, May 2014, http://mfol.ece.ntua.gr/communication-radar-signal-processing-systems/.)

As threats to the homeland and allies become more difficult to detect, track, and discriminate, conventional radars may not necessarily provide the best means of contending with adversary systems.[14] Most current radars within the BMDS are monostatic; thus, the utilization of supplementary, inexpensive CubeSat receivers could enhance performance across the kill chain.[15]

One key advantage of a monostatic system is the use of interferometry to obtain and process multiple target measurements and supply greater azimuthal discrimination.[16] A notable disadvantage of such a system is its low resilience to specific countermeasures. Figure 3 illustrates how a stealthy target, based on its design, creates a difficult angle of view for a monostatic node (shown at left), while the other receivers' angles of view are more conducive to detecting the target.[17]

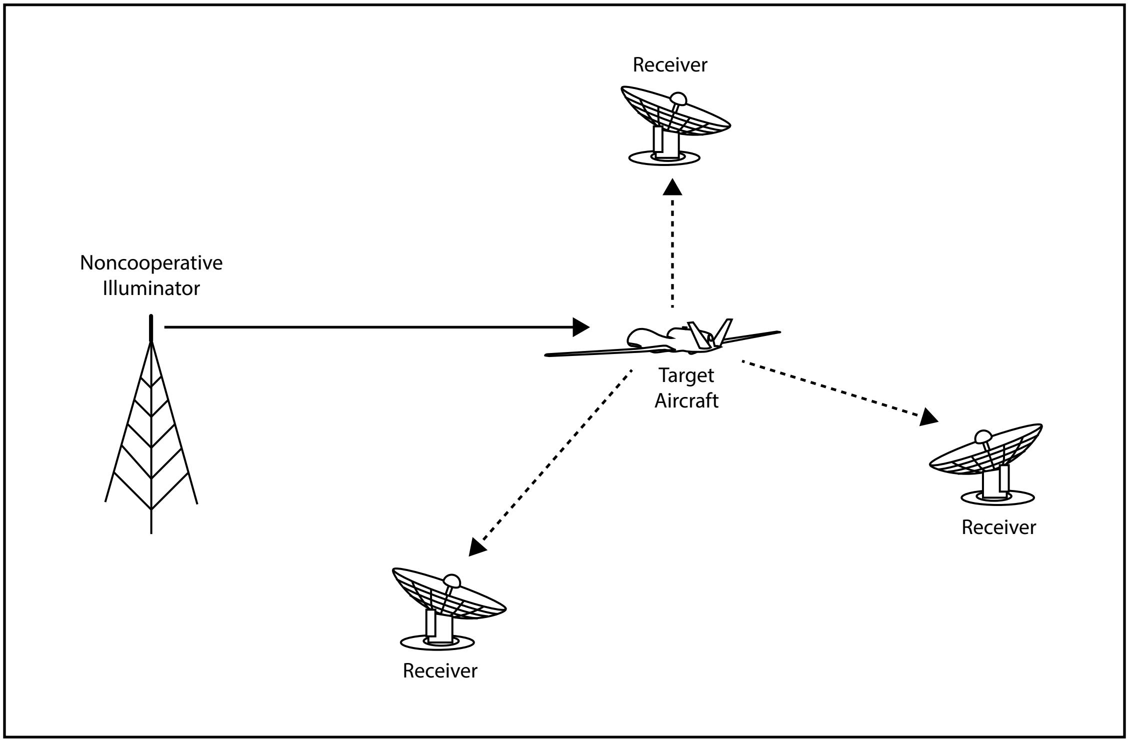


Figure 3. Detection of a target using multistatic radar

Multistatic methods may greatly enhance and supplement the detection, track (through cues), and discrimination functions of existing BMDS assets. The CubeSat community has investigated the use of networked sensors, but to date no organization has produced a multistatic CubeSat network.[18] One approach might use ground-based illuminators to reduce the burden on small satellites with limited apertures, thus providing extended detection or improved discrimination compared to the capability of current systems.

Overview of CubeSat Technology

A single-unit "U" CubeSat is a 10 centimeter (cm) cube with a mass of up to 1 kilogram (kg). The primary mission of a CubeSat host is to offer access to space for small payloads. General features of all CubeSats are as follows:

- Each single CubeSat may not exceed 1 kg mass.
- The center of mass must be within 2 cm of its geometric center.
- Double and triple configurations are possible. In this case, the allowable mass is 2 kg or 3 kg, respectively. Only the dimensions in the Z axis change.

- Another approach is referred to as “swarming” (i.e., using clusters of CubeSats to obtain improved performance from the collective system).

Figure 4 details an isometric drawing of a CubeSat as well as an artist’s rendition of a CubeSat in orbit.[19]

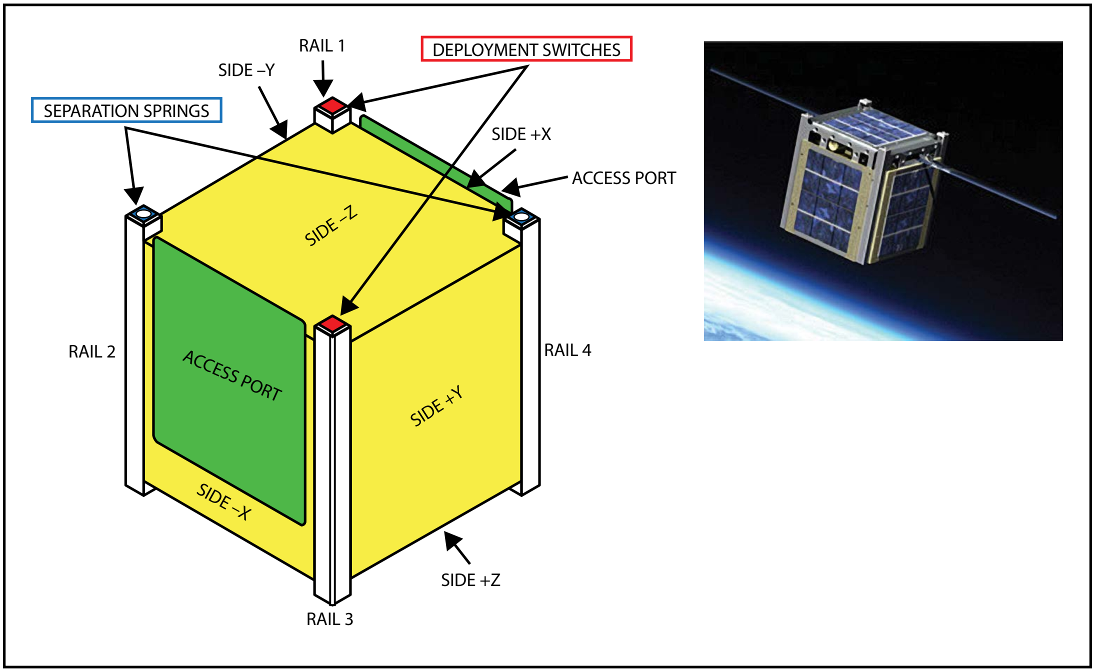


Figure 4. CubeSat image. (Reprinted from Riki Munakata, CubeSat Design Specification Rev 12 [public domain] [San Luis Obispo, CA: California Polytechnic State University, 2009], 10.)

The CubeSat concept was proposed publicly in 2000, and the first satellites launched in 2003. By the end of 2012, more than 100 CubeSats were launched. Today a significant share of the manifests are filled by US DOD-sponsored and industry-built CubeSat missions. Various agencies in the DOD experienced success with early CubeSats (e.g., the Aerospace Corporation’s Aerocube series and Boeing’s CSTB-1).[20] The division of CubeSats over the years clearly indicates that the use of this type of host for military applications is increasing (fig. 5).[21]

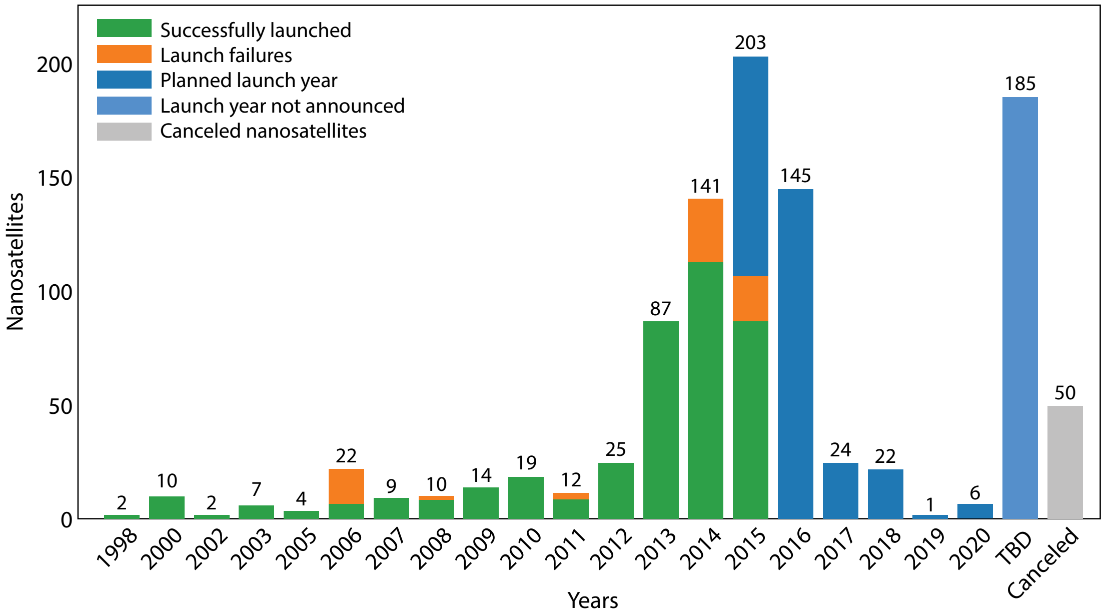


Figure 5. Small satellites by launch year. (Reprinted from "Figures," Nanosatellite Database by Erik, accessed 4 December 2015, http://www.nanosats.eu/.)

Spectral Sensor Miniaturization

Many universities and laboratories are working to advance miniaturization in the form, fit, and function as well as in aspects of the development of spectral sensor algorithm processing. Miniaturization of a hyperspectral sensor calls for consideration of at least three aspects: physical features, software algorithms, and overall viability on a CubeSat-hosted platform. Research on placing this type of sensor in a standard 3U (10 cm x 10 cm x 30 cm) CubeSat envelope has already begun, and many of the primary components are readily available as COTS items. Compression techniques must be utilized to extract the key spectral components of the scene (what the sensor sees) since the data sizes are significant, especially considering the SWaP limitations of CubeSats.

Sensor and Algorithm Development and Modeling

The resulting spectral data cube of an area of interest represents a significant amount of data (one gigabyte or more for a scene), and the digital storage and transmission of these data from orbit constitute a sizable task, even for large-scale modern satellites. Mitigating this large volume of data involves a considerable amount of effort focused on developing computationally based compression techniques for the storage and transmission of hyperspectral data.[22]

Fit, Form, and Function Trade Space

The effectiveness of a proposed multistatic sensor CubeSat network will depend upon a number of factors, including, but not limited to

- the number of CubeSats in the multistatic sensor constellation;
- the availability and capability of the CubeSats;
- CubeSat coverage/distance from intended target at any given time;
- the ability to obtain stereo or multisatellite fused coverage;
- the agility of the sensor and tasking/reporting chains;
- link budget and transmit power of the CubeSats;
- intracommunication technology;
- sensitivity of the ground-station (processing station) receiver; and
- the availability of ground stations for processing multi-aspect CubeSat sensor data.

Development of Multistatic Sensor Algorithms

As with any system that collects and fuses information from multiple sources, the development of multistatic sensor algorithms will prove daunting. Processing will require tailoring to specific mission needs or the ability to update quickly, based on dynamic changes to threat scenes.

To some extent, the MDA's space-based kill assessment experiment is analogous to the ideas presented in this article. The assessment will use a commercially available satellite constellation to host payloads that detect and verify the negation of threat missiles.[23]

Persistent Coverage

CubeSats yield a relatively low-cost mechanism to position specific sensor technologies by using the principles of orbital mechanics. CubeSats can increase the probability of obtaining data to support target-signature exploitation for various military applications. For an example of a commercial venture utilizing the CubeSat platform, one should look to Planet Labs, which recently launched a 28-CubeSat constellation into low Earth orbit for the purpose of providing five-meter-resolution color spatial images of the earth on demand and at high temporal repetition rates. Planet Labs did so with initial private funding of $65 million, far less than the cost of a single "traditional" satellite.[24]

Supply Chain Assessment

Miniaturization by innovative technology companies from all industries has enabled an increase in CubeSat capabilities. This technological progression has made it possible to conduct larger space-research experiments with smaller systems.

There is no indication that this trend towards smaller size will cease in the near future as research and micromanufacturing of components continue to become smaller and more powerful. This new industry has had the effect of overwhelming conventional launch resources.[25] The utility of small satellites is expanding in large part due to the aforementioned advances, greater sophistication of COTS components, and a mind-set change in satellite design driven by adoption of the CubeSat specification.[26] Space access opportunities for small satellites are limited to rideshare opportunities on small-, medium-, and heavy-lift space-launch boosters serving primary payloads.[27]

With limited launch resources, constellation modeling can identify persistent coverage of areas of interest. Additionally, the limited life cycle of each CubeSat platform warrants a complete supply-chain (procurement, manufacturing, and distribution) assessment to determine the viability, overall cost of building additional hardware and replacement, timelines, and feasibility of maintaining that persistent coverage.

Strategic Alignment of Integrated Sensing, Processing, and Exploitation

The emerging threat landscape is decisively global, bringing with it new challenges that must be addressed. Our adversaries, including both state and nonstate actors, are becoming more sophisticated and are actively attempting to degrade and deny our access. We must pursue innovative solutions that give us an advantage in both decision and agility. Additionally, the nation's fiscal constraints demand that government agencies make judicious decisions about where, why, and how every dollar is spent, resulting in increased emphasis on the affordability and efficiency of intelligence, surveillance, and reconnaissance (ISR).

A trend in the ISR environment is the increasing rate of commercial innovation and the resulting democratization of technology. This tendency offers a unique opportunity to integrate and leverage new and novel sources of information outside our span of control to guide the ISR capabilities within our span of control, obtain information in contested environments, and ultimately increase our enterprise-level affordability, efficiency, and effectiveness. Mobile targets and the dynamic threat landscape motivate the need for real-time intelligence, situational awareness, and decision making. After becoming the Air Force's first deputy chief of staff for ISR, Lt Gen David Deptula remarked that, today, "intelligence is operations."[28] The value of single-source intelligence is rapidly diminishing.

Opportunities remain to support efforts to gain efficiencies in sensing: Can SWaP-C of sensors and platforms be reduced to bend the cost curve and enable new applications via distributed sensing? How can the industry affordably, efficiently, and effectively leverage commercial, uncooperative, and nontraditional sources within the broader ISR enterprise? What cost-effective sensors and sources could be most transformed in intelligence value through exquisite algorithms and processing? How do we determine the optimal collection strategy to make inferences and reduce uncertainty about a specific activity? At some point, the community must address the broader issues across the entire spectrum of doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy. Concepts of operations, system architecture, training, test, launch, transition, operator acceptance, operations and maintenance, command and control, tasking priorities, data paths, replenishment, upgrades, disposal, and so forth, are just a few of the many factors that must be considered during the engineering of space systems.

The outcome of further study across the community will inform what portions are feasible and those that are not practical. Both feasibility and nonfeasibility outcomes are critical so that time and effort are not spent on items of little return. Once feasibility has been determined, then more practical research and development can begin in earnest.

Success will demonstrate that CubeSats can add differentiated value in this critical area and support the missile defense war fighter. Target-signature detection and exploitation through use of CubeSat technology hosting hyperspectral sensing and/or multistatic payloads will directly benefit various sponsors, including the MDA, military, and other agencies. Although separate organizations may have different requirements, similar solutions may more efficiently offer coordinated support not only for space-based discrimination but also for space situational awareness and protection.

Research should continue to investigate and attempt to demonstrate the convergence of low-cost, overhead-deployment technology and low-power, lightweight payloads that could augment other systems. As with most emerging technologies, future development efforts will determine the true scope and utility of CubeSats to enhance and improve the nation's overhead architecture and assist the MDA's highest-priority mission in defending the homeland and forces assigned around the world from ballistic missile attack. ✪

Notes

1. Maj Stacie Shafra, "JFCC-Space Commander Highlights Need for Improved Space Situational Awareness," US Strategic Command, 23 February 2011, http://www.stratcom.mil/news/2011/221/JFCC-Space_commander_highlights_need_for_improved_space_situational_awareness/.

2. Anthony J. Tambini, *Wiring Vietnam: The Electronic Wall* (Lanham, MD: Scarecrow Press, 2007).

3. Department of Defense, *Defense Acquisition Guidebook* (Washington, DC: Department of Defense, 2013), https://dag.dau.mil.

4. "About NGA," National Geospatial-Intelligence Agency, accessed 2 December 2015, https://www.nga.mil/About/NGAStrategy/Pages/default.aspx.

5. Senate, *General William L. Shelton, Statement to the Senate Armed Services Committee*, 113th Cong., 1st sess., 24 April 2013.

6. P. Ehrenfreund, R. C. Quinn, and A. J. Ricco, "CubeSats as Innovative Science Platforms," *Journal of Small Satellites* 2, no. 1 (July 2013): 79–81.

7. "Our Story," Planet Labs, accessed 2 December 2015, https://www.planet.com/story/.

8. Herbert J. Kramer and Arthur P. Cracknell, "An Overview of Small Satellites in Remote Sensing," *International Journal of Remote Sensing* 29, no. 15 (2008): 4285–337.

9. Michael Fogle Jr., J-M Wersinger, and Luke Marzen, Auburn University Proposal investigators, "Development of a Hperspectral Instrument for CubeSats for Earth Remote Sensing" (grant proposal),

2014; and Marin Halper, William F. Basener, and Shannon D. Jordan, *On the Probabilistic Identification of Solid Materials in HyperSpectral Imagery* (McLean, VA: MITRE Corporation, 2013).

10. "Contamination Characterization through Airborne Hyperspectral Imaging," Missouri Resource Assessment Partnership, accessed 2 December 2015, http://morap.missouri.edu/index.php/contamination-characterization-through-airborne-hyperspectral-imaging/.

11. Halper, Basener, and Jordan, *Probabilistic Identification*.

12. Chris J. Baker, "An Introduction to Multistatic Radar," in *Multistatic Surveillance and Reconnaissance: Sensor, Signals and Data Fusion*, RTO-EN-SET-133 (Brussels: NATO Science and Technology Organization, April 2009), 2-1–2-20, https://www.cso.nato.int/pubs/rdp.asp?RDP=RTO-EN-SET-133.

13. Ibid.

14. Chris J. Baker and H. D. Griffiths, "Bistatic and Multistatic Radar Sensors for Homeland Security," in *Advances in Sensing with Security Applications*, ed. Jim Byrnes and Gerald Ostheimer (Dordrecht, Netherlands: Springer, 2006), 1–22.

15. Missile Defense Agency, *Programmatic Environmental Impact Statement* (Washington, DC: Missile Defense Agency, 2007).

16. J. L. Glaser, "Fifty Years of Bistatic and Multistatic Radar," *IEEE Proceedings* 133, no. 7 (December 1986): 596–603.

17. Baker, "Introduction to Multistatic Radar."

18. QB50, an FP7 Project, accessed 2 December 2015, https://www.qb50.eu/index.php/project-description-obj.

19. Riki Munakata, *CubeSat Design Specification Rev 12* [public domain] (San Luis Obispo, CA: California Polytechnic State University, 2009), 10; and Giovanni Motta, Francesco Rizzo, and James A. Storer, *Hyperspectral Data Compression* (Dordrecht, Netherlands: Springer-Verlag, 2005).

20. David Hinkley, "Picosatellites at the Aerospace Corporation," in *Small Satellites, Past, Present and Future*, ed. Henry Helvajian and Siegfried W. Janson (El Segundo, CA: Aerospace Press, 2009), 151–73.

21. M. A. Swartwout, "The First One Hundred CubeSats: A Statistical Look," *Journal of Small Satellites* 2, no. 2 (December 2013): 213–33.

22. Fogle, Wersinger, and Marzen, "Development of a Hperspectral Instrument"; and Motta, Rizzo, and Storer, *Hyperspectral Data Compression*.

23. Mike Gruss, "MDA Kill Assessment Sensors Would Be Commercially Hosted," *Space News*, 20 March 2015, http://spacenews.com/mda-kill-assessment-sensors-would-be-commercially-hosted/.

24. Fogle, Wersinger, and Marzen, "Development of a Hperspectral Instrument"; and "Our Story," Planet Labs.

25. R. A. Deepak and R. J. Twiggs, "Thinking Out of the Box: Space Science beyond the CubeSat," *Journal of Small Satellites* 1, no. 1 (January 2012): 3–7.

26. Kirk Woellert et al., "CubeSats: Cost-Effective Science and Technology Platforms for Emerging and Developing Nations," *Advances in Space Research* 47, no. 4 (15 February 2011): 663–84.

27. Kirk Woellert, "Space Access: Still the Major Issue for the Small Satellite Community," *Journal of Small Satellites* 1, no. 2 (October 2012): 45–47.

28. Lt Gen David A. Deptula, "Transformation and Air Force Intelligence, Surveillance, and Reconnaissance" (remarks at the Air Force Defense Strategy Seminar, Washington, DC, 27 April 2007), http://www.af.mil/AboutUs/Speeches/Display/tabid/268/Article/143960/transformation-and-air-force-intelligence-surveillance-and-reconnaissance.aspx.

Dr. Jeremy L. Barnes, PMP

Dr. Barnes (BS, MS, PhD, Auburn University; MS, University of Alabama in Huntsville) has multiple years of experience in command and control and space-based processing with the Missile Defense Agency. He has contributed to several of the nation's critical ballistic missile defense programs, including Ground-Based Midcourse Defense; Command and Control, Battle Management, and Communications; and Terminal High Altitude Area Defense. A member of NASA's Alabama Space Grant Consortium, he also worked with Auburn University faculty members to implement a system engineering approach to the university's student space program. In addition to employment at the MITRE Corporation, Dr. Barnes instructs undergraduate and graduate courses at the University of Alabama in Huntsville.

Ashley N. Elledge

Mr. Elledge (BS, MS, University of Alabama in Huntsville) has 15 years of professional experience. In 1999 he began an internship with the Boeing Company and, following graduation from college, worked with Boeing as an electrical engineer supporting avionics test and instrumentation system design for the Ground-Based Midcourse Defense (GMD) program. He joined Raytheon in 2004 and performed data analysis for exoatmospheric kill vehicle simulations in the GMD System Test Laboratories. Since November 2005, Mr. Elledge has worked for the MITRE Corporation as a systems engineer on multiple projects, including Link 16 to Army aviation integration; Command, Control, Battle Management, and Communications; GMD; Terminal High-Altitude Area Defense; and the Ballistic Missile Defense System (BMDS) Capability Assessment (BCA) Team.

Col Scott G. Patton, USAF, Retired

Colonel Patton (BME, Georgia Institute of Technology; MBA, University of Colorado; MS, Marine Corps University) works for the MITRE Corporation as a project manager in Huntsville, Alabama, supporting the Missile Defense Agency's Ground-Based Missile Defense Strategic Systems Engineering Division.

Let us know what you think! Leave a comment!