Small Satellites: The future of Earth observation and space exploration missions

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Abstract

Earth orbiting satellites come in a wide range of shapes and sizes in order to meet a diverse variety of uses and applications. While the larger of these satellites with masses exceeding 1000kg support high resolution remote sensing of the Earth, high bandwidth communications services and world-class scientific studies, they take a long time in development and are overly expensive to build and deploy. Consequently, interest in the smaller-sized satellites has skyrocketed in recent years. Their reduced development time and launch costs, compared to conventional large satellites, have made them an excellent replacement in many areas. This article dives into this technology and how it represents a bright future for space exploration and Earth observation missions.

Background

The exploration and exploitation of space has been a costly endeavor, yet it has undoubtedly yielded a vastly improved understanding of our planet, our solar system and the wonders of the universe. Building satellites required technically advanced and expensive capabilities, launchers were likewise costly and risky, and the ground infrastructure was complex. These factors limited our access to space travel to only the most advanced and wealthy of nations. Small satellites (500 kg or less) have been around for over half a century, but interest in their exploitation is growing now more than ever. Since how big a satellite corresponds directly to expenditures related to materials and parts, labor for development, and launch vehicle fuel, it naturally follows that the principal advantages of small satellites over their counterparts are lower overall costs and shorter times for development. Nevertheless, small satellites have technological and mission-related advantages in their own right. The shorter development cycle allows for the insertion of the newer payload and bus technologies. In addition, compared to a single large satellite, a network of several small satellites is potentially more flexible, as it can be reconfigured according to mission needs. Small satellites and specifically, cubesats (Nano Satellites), are also an opportunity for less advanced countries to begin their path in the Space Technology Ladder. These satellites provide a relatively simple, low-risk and quick method of independently gaining foundational experience in space technologies.

Class	Mass (kg)
Large satellite	>1000
Small satellite	500 to 1000
Mini-satellite	100 to 500
Micro-satellite	10 to 100
Nano-satellite	1 to 10
Pico-satellite	0.1 to 1
Femto-satellite	<0.1

Table 1: general classification of femto-pico-nano-micromini-small-large satellites

Small Satellites Capabilities Development

Since the dawn of the space era, Small satellites skyrocketed in development. New technologies and capabilities were introduced to bolster the applications in different categories: communication, Earth Observation, Space Exploration, weather monitoring, etc. The early small satellites lacked solar cells and completely depended on simple batteries to perform their tasks, it wasn't long before the Solar cells and rechargeable batteries got adopted to accommodate for the short comings of the battery-operated ones in orbit. The passive attitude stabilization techniques were then added to the small satellites. Some of the most significant being spin stabilization and gravity gradient. Those aforementioned techniques depended on the electricity generated from solar panels to control the satellite and keep it tracking its target using reaction wheels that change their rate of spinning creating a torque that shifts the satellite's orientation.

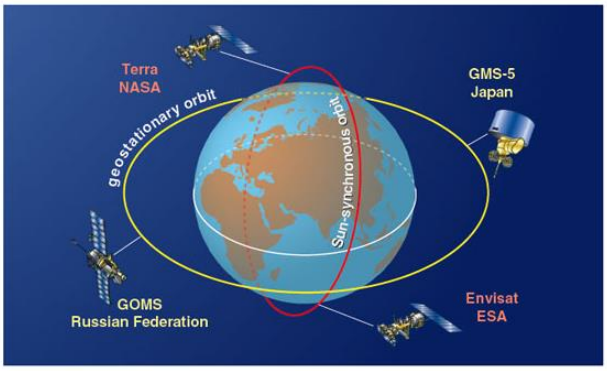

Figure 1: An illustration for the most used orbits in Earth observing satellites, Geostationary and Sun-Synchronous

The advancements in the small satellites' buses did not only provide a greater degree of flexibility but it also enabled more satellites to utilize new payload technologies. The transition to the modern, reprogrammable small satellite first began in 1981 with the launch of a 54kg micro-satellite UoSAT-1 (UoSAT-OSCAR-9) that consisted of two in-orbit reprogrammable microcomputers. Moreover, its on-board RCA1802 and Ferranti F100L microcomputers were launched empty of software, except for a 'boot loader', and a series of programs were subsequently compiled on the ground and were later uploaded to the satellite. The above example illustrates the key impact made on the capability and utility of small satellites through the introduction of early in-orbit reprogrammable microprocessors.

As microsatellite technical capabilities gradually developed throughout the 1990's, interest grew in their use for technology demonstration and verification, new digital services prior to widespread internet infrastructure, rudimentary Earth observation, radio science and military applications and, in particular, training programs for developing space nations. For instance, South Africa developed and deployed SunSat satellite, the first satellite in all developing countries. The satellite included a GPS receiver, laser reflectors, magnetometers, star camera, Amateur Radio communications and a 15 m resolution, 3456 pixel, 3-band push broom imager. Several images were

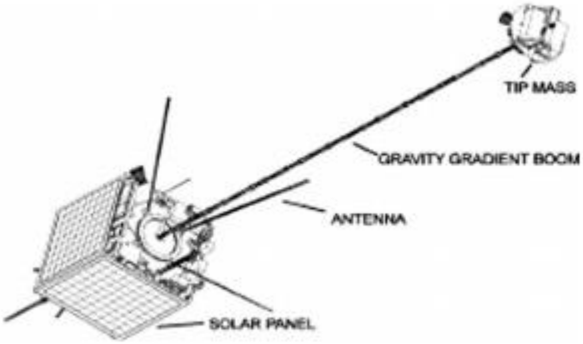

Figure 2: South Africa first small satellite, the SunSat

successfully taken and transmitted to the ground from SUNSAT satellite. Unfortunately. It didn't take long for the satellite to exit orbit, but the country had benefited from the developed technology.

Small Satellites for Earth observation (Earth Remote sensing)

For earth observations sensors are a must, their purpose is to sense reflections of the earth within the range of the electromagnetic spectrum; the majority of Earth-observation satellites carry "passive" sensors, measuring either reflected solar radiation or emitted thermal energy from the Earth's surface or atmosphere. Active sensors (such as radar), however, require antennas for transmission of electromagnetic pulses and for reception of the backscattered reflections from the ground. Of course, due to the lack of complicated components and equipment, passive sensors require less mass and are therefore more preferred in small satellite EO missions. As a result, Earth observation satellites prefer sun synchronous polar orbits at orbital heights between 400 and 1000 km. This choice of orbit ensures perfect illumination conditions. However, passive sensors are challenging some limitations, such as:

- Spatial resolution of the optical system, which is controlled by the diffraction limitation.
- Sensitivity of the detector elements that require at least about 1 millisecond exposure time.
- Image motion, because of the forward motion of the satellite in the order of 7.4 km/sec or 7.4 m/msec.

Fortunately, passive sensors are becoming more advanced leading to an increase in spatial, spectral and temporal resolution. In addition, image motion compensation became possible by time delay integration sensors (TID) or by rotation of the satellite sensor during the exposure time.

Satellite constellations for global coverage

Small satellites provide a unique opportunity for affordable constellations to achieve global coverage on Earth with high time resolution. In this point, small satellites can do things that are impractical with large satellites.

Satellite constellations provide a number of advantages like:

- Increase of time resolution depending on the number of satellites in the constellation.
- The relative low cost of a single satellite makes the replacement of a satellite in a formation or a constellation easier.
- Soft degradation of the performance of the system resulted from the malfunction of one satellite.

Figure 3: The five satellites of RapidEye constellation

The commercial RapidEye constellation may serve here as an example of a constellation's capability. The mission provided a commercial operational GIS (Geographic Information System) service along with high-resolution multispectral imagery. The objectives are to provide a range of EO products and services to a global community. The five observation satellites of RapidEye Earth mission have been launched on a single Russian Dnepr rocket in August of 2008, which proves the point of less costly launch missions (launching five satellites on a single time) and they are deployed in orbits at an altitude of 630 km. The satellites are placed such that the spaces between the satellites are equal in a single sun synchronous orbit to ensure a short revisit time and consistent imaging conditions. The satellites follow each other in their orbital plane at about 19 min interval.

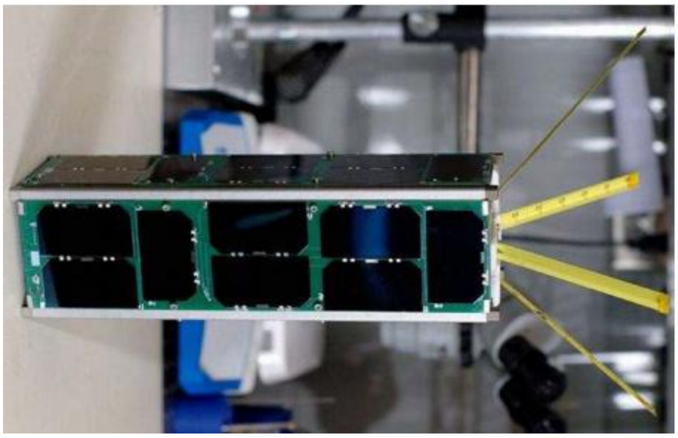

Figure 4: RAX CubeSat

Distributed small satellites can also be used for missions unachievable using a monolithic approach. Such missions have the purpose of studying the variations of a parameter using the intersatellite range change measurements and attitude measurements from each satellite rather than multiplying the payloads for coverage enhancement.

CubeSats for space exploration

CubeSats represent a specific type of nanosatellite measuring 10×10×10 cm3 and weighing slightly more than 1 kg (typically less than 1.33 kg). Their small size and mass make them relatively inexpensive and simpler to build and allow them to be launched as secondary payloads at much lower cost and higher frequency than traditional monolithic satellites. The standard CubeSat size of 1U (10×10×10cm3) has been scaled to other configurations such as the 2U (20×10×10 cm3), 3U (30×10×10 cm3) , 6U and 12 U.

CubeSats can play a supportive role in exploration activities. Several pioneering CubeSat missions have recently demonstrated the ability to conduct scientific experiments in the fields of biology and Earth observation; also, they are currently used in other missions related to space exploration such as planetary science and space weather.

CubeSats are also being used to demonstrate technologies for future space exploration, in particular solar sail propulsion and electric propulsion. Moreover, it is envisaged that CubeSats will piggyback on main orbiters traveling to Mars and the Moon to assist planetary science missions. A worldwide CubeSat program exploration and integration that supports space nations in a significant way will prepare for a future global space exploration program with more participants.

Challenges & Conclusion

Launching to orbit still represents a constraint in small satellite missions. Most of the projects are launched as a secondary payload on launchers for large spacecraft. Small launchers are still under development to become able to survive the aggressive first 20 minutes or so of ascending to orbit. Moreover, in-orbit data processing, communication, and storage need to be improved.

Present day small satellites in many instances now compete and in some aspects surpass traditional large satellites' capabilities but at a fraction of the cost; however, small satellite missions do not replace large satellite missions, as their goals and issues are often different, to be more accurate they complement them. There is a similar relation between small and large satellites as exists between microprocessors and supercomputers: some problems are better addressed via distributed systems, for example, constellations of small satellites (typically used for global coverage), while others may require centralized systems (e.g. a large optical instrument, as in a space telescope or a high-power direct broadcast communications system). To sum it up, small satellites represent a bright future for the space exploration and Earth observation missions in a lot of sides where large satellites are not the appropriate option.

References

[1] M. N. Sweeting, "Modern Small Satellites-Changing the Economics of Space," Proceedings of the IEEE, vol. 106, no. 3, pp. 343–361, 2018.

[2] M. Ansdell, P. Ehrenfreund, and C. Mckay, "Stepping stones toward global space exploration," Acta Astronautica, vol. 68, no. 11-12, pp. 2098–2113, 2011.

[3] M. B. Argoun, "Recent design and utilization trends of small satellites in developing countries," Acta Astronautica, vol. 71, pp. 119–128, 2012.

[4] R. Sandau, "Status and trends of small satellite missions for Earth observation," Acta Astronautica, vol. 66, no. 1-2, pp. 1–12, 2010.

[5] W. Shiroma, L. Martin, J. Akagi, J. Akagi, B. Wolfe, B. Fewell, and A. Ohta, "CubeSats: A bright future for nanosatellites," Open Engineering, vol. 1, no. 1, 2011.25, 2020, from https://science.jpl.nasa.gov/PlanetaryScience/PlanetaryAtmospheres/projects.cfm

[6] R. Sandau, H.-P. Roeser, and A. Valenzuela, Small Satellite Missions for Earth Observation New Developments and Trends. Berlin: Springer Berlin, 2014.

[7] R. Sandau, "High-resolution imaging with small satellites: what are the possibilities and limitations?," Sensors and Systems for Space Applications, 2007.