Journal of Instrumentation, Automation, and Systems, 2023,
Vol.10, No.3

Nanosat Technology Survey & Its Applications

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Abstract— This paper provides a comprehensive survey of nanosatellite technology and its various applications. The study covers the current state-of-the-art in nanosatellite design, development, and deployment, including recent advances in miniaturization and cost reduction. In this paper, we provide a comprehensive survey of the technologies of nanosatellites and their applications such as remote sensing, communication, and scientific research. We start by discussing the design and structure of nanosatellites, including the various subsystems such as power, communication, and propulsion.

We also discuss the challenges and limitations of nanosatellites, such as the limited size and weight of these satellites and the limited duration of their missions. Finally, we explore the future of nanosatellites and the potential for further development and innovation in this field. Our survey provides a comprehensive overview of the current state of the art in nanosatellites and highlights the potential of these small satellites operating in a constellation for a wide range of applications.

Keywords— nanosatellite, cubesat, surveillance, communication, IoT

DOI : 10.5281/zenodo.11651411

I. INTRODUCTION

NANOSATELLITES are small satellites with a mass range from 1 to 10 kilograms. Over the past two decades, the development of nanosatellites has seen significant advances, leading to a growing interest in this technology for various applications. The miniaturization of electronic components, advances in materials science, and the growth of commercial space ventures have all contributed to the growth of this field.

Nanosatellites offer numerous benefits over traditional large satellites, including lower costs, faster deployment times, and the ability to be launched as secondary payloads on larger missions. These advantages have enabled new and diverse applications, ranging from remote sensing and communication to scientific research and technology demonstrations.

Despite the potential of nanosatellites, there are still many technical and operational challenges that must be addressed. This paper provides a comprehensive survey of the current state-of-the-art in nanosatellite technology and its applications. The study covers the design, development, and deployment of nanosatellites, as well as recent advances in miniaturization and cost reduction. Additionally, the paper explores the various applications of nanosatellites and highlights their potential to revolutionize the space industry.

The goal of this paper is to provide a comprehensive overview of the field of nanosatellite technology and its applications. The study aims to bring together the latest developments in this area, including the challenges and future directions for the development and deployment of nanosatellites. By doing so, the paper provides a valuable resource for researchers, engineers, and decision-makers interested in the field of nanosatellites.

The next section provides a literature study about nanosatellites that underscores their transformative impact on space missions. From enabling cost-effective Earth observation and scientific research to democratizing access to space and enhancing military capabilities, nano-satellites have proven to be a versatile and valuable asset in the space industry. As technological advancements continue, the applications and capabilities of nano-satellites are expected to expand, further cementing their role in the future of space exploration and utilization.

In section III, we address the primary challenges in the development of nanosatellite technology, such as miniaturization limitations, cost reduction, and the need for compact, reliable power sources, along with the obstacles in designing efficient microelectronics and payloads. Section IV outlines the design process, covering critical subsystems like orbit, structure, power, propulsion, communication, avionics, payload, command and data handling, and thermal control, emphasizing the integrated system necessary for successful nanosatellite operation. The section discusses the parameters

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This paper was submitted on Feb 14, 2023; revised on May 15, 2023, and accepted on Sep 22, 2023.

defining nanosatellite orbits, CubeSat structure, power module, and propulsion systems, and communication modules. Section V presents the practical applications of nanosatellites, such as remote sensing, scientific research contributions, communication services in remote areas, air and sea traffic management, and collaborative networked platforms. Section VI discusses the significant advancements and insights from the study, emphasizing the rapid evolution and impact of nanosatellites in communication, earth observation, and scientific research, particularly in disaster response, agriculture, and environmental monitoring. Section VII concludes by highlighting the benefits and challenges of nanosatellite technology, such as cost-effectiveness, rapid deployment, manageable failure risks, and multi-purpose functionality, against challenges like orbit altitude maintenance, capacity limitations, and environmental impact, emphasizing their revolutionary potential in space research and applications.

II. Literature Study

Nano-satellites, often referred to as small satellites or CubeSats, have emerged as a significant innovation in the field of space technology. These miniature satellites, typically weighing between 1 and 10 kilograms, offer a cost-effective and efficient solution for various space missions. The development and application of nano-satellites have been extensively studied and documented in the literature, highlighting their technological advancements and diverse applications.

The development of nano-satellite technology has been driven by institutions such as NASA-GSFC, which has been at the forefront of this innovation since the late 1990s. Panetta et al. (1998) detailed the early efforts in nano-satellite technology development at NASA-GSFC,[1] emphasizing the potential of these small satellites to perform complex missions at a fraction of the cost of traditional satellites. Esper et al. (2000) further explored NASA-GSFC's efforts,[2] showcasing how nano-satellite technology can be applied to Earth science missions, providing valuable data for environmental monitoring and research.

Table 1 Literature study on nanosatellites, its related technologies, and applications

Key Point / Theme	Paper Title	Authors
Early Development of Nano-Satellite Technology	NASA-GSFC Nano-Satellite Technology Development	Panetta, Peter, et al. (1998) [1]
	Developments in Nano-Satellite Structural Subsystem Design at NASA-GSFC	Rossoni, Peter, and Peter V. Panetta (1999) [25]
	NASA-GSFC Nano-Satellite Technology for Earth Science Missions	Esper, Jaime, et al. (2000) [2]
Nano-Satellites in the "New Space" Paradigm	Nano and Micro Satellites as the Pillar of the "New Space" Paradigm	İnce, Fuat (2020) [3]
	Design of a University Nano-Satellite: The PiCPoT Case	Del Corso, Dante, et al. (2011) [5]
	Design Solutions for a University Nano-Satellite	Passerone, Claudio, et al. (2008) [6]
Micro and Nano-Satellite Constellations	A Review on the Development of Micro-Nano Satellite Constellation and Formation Flying Technologies	Shu-jian, Sun, et al. (2017) [4]
	Recent Development of Nano-Satellite Constellation as IoT Communication Platform	Gaikwad, Mahendra, et al. (2022) [12]
	NetSat—Challenges and Lessons Learned of a Formation of 4 Nano-Satellites	Scharnagl, Julian, et al. (2022) [26]
Applications in Earth Science and Observation	Study of the Future Perspectives of Micro and Nano-Satellite Constellations in the Earth Observation Market	Costa Rabionet, Mariona (2019) [9]
	Micro/Nano-Satellites: Opportunities and Challenges	Xiaoqian, Chen, et al. (2019) [27]
Scientific Research and Earth Monitoring	A Nano-Satellite to Study the Sun and the Earth	Meftah, Mustapha, et al. (2014) [11]
	Applications of Nano-Satellites and Cube-Satellites in Microwave and RF Domain	Simons, Rainee N., and Kavita Goverdhanam (2015) [8]
	Doing Science with Nano-Satellites	Gregorio, Anna, et al. (2018) [28]
Educational and Hands-On Experiences	Evolution from Education to Practical Use in University of Tokyo's Nano-Satellite Activities	Nakasuka, Shinichi, et al. (2010) [10]
	ETSIT-UPM Experiences in Hands-On Nanosatellite Activities	Martínez, Ramón (2012) [19]
	Launch Management of a Nanosatellite for Bolivia	Puma-Guzman, Rosalyn, and Jorge Soliz (2021) [20]
Military and Disaster Management Applications	SMALL SATELLITE: MILITARY APPLICATIONS	Danish, Muhammad Nauman [13]
	The Effectiveness Evaluation of Nano-Satellites Used in Military Operations	Tang, Ya-Feng, and Xiao-Hong Yu (2013) [14]
	Using Support Vector Machine (SVM) with GPS Ionospheric TEC Estimations to Potentially Predict Earthquake Events	Asaly, S.; Gottlieb, L.-A.; Inbar, N.; Reuveni, Y. (2022) [51]
Technological Advancements in Subsystems	Nano-Satellites, a Fast Way to Pre-Qualify New Micro-Technology	Hamann, R. J., Chris J. M. Verhoeven, et al. (2005) [7]
	Survey of Worldwide Pico- and Nanosatellite Missions, Distributions and Subsystem Technology	Bouwmeester, J., and J. Guo (2010) [24]

The evolution of nano-satellite technology has been closely linked to the broader "New Space" paradigm, which emphasizes the democratization and commercialization of space. İnce (2020) described how nano and micro-satellites are pivotal to this paradigm,[3] enabling a wide range of actors, including academic institutions and private companies, to participate in space missions. This democratization is further evidenced by the increasing number of university-led nano-satellite projects. Del Corso et al. (2011) and Passerone et al. (2008) discussed the design and development of university nano-satellites,[5][6] highlighting the educational and research opportunities they provide.

Technological advancements in nano-satellites have also focused on the development of micro and nano-satellite constellations and formation flying technologies. Shu-jian et al. (2017) reviewed the progress in this area,[4] noting the potential for these constellations to enhance global communication networks and Earth observation capabilities. Similarly, Gaikwad et al. (2022) examined the role of nano-satellite constellations as platforms for IoT communication,[12] underscoring their importance in the rapidly growing Internet of Things (IoT) ecosystem.

The applications of nano-satellites are vast and varied. Simons and Goverdhanam (2015) explored the use of nano-satellites in the microwave and RF domain,[8] demonstrating their utility in scientific research and communication. Meftah et al. (2014) described a nano-satellite designed to study the Sun and Earth,[11] illustrating the scientific potential of these small satellites. In the realm of Earth observation, Costa Rabionet (2019) analyzed the future perspectives of micro and nano-satellite constellations,[9] emphasizing their potential to revolutionize the Earth observation market by providing high-resolution imagery and real-time data.

The use of nano-satellites in educational and hands-on activities has also been a significant focus. Nakasuka et al. (2010) highlighted the University of Tokyo's experience with nano-satellite activities,[10] showcasing the transition from educational tools to practical applications. Martínez (2012) and Puma-Guzman and Soliz (2021) discussed the hands-on experiences of various institutions in developing and launching nano-satellites,[19][20] providing valuable insights into the educational benefits and challenges associated with these projects.

Moreover, nano-satellites have found applications in military operations and disaster management. Danish (2022) and Tang and Yu (2013) evaluated the effectiveness of nano-satellites in military contexts,[13][14] demonstrating their potential for reconnaissance, communication, and situational awareness. Asaly et al. (2022) investigated the use of nano-satellites in predicting earthquake events using ionospheric data,[21] highlighting their potential in disaster management and early warning systems.

The development of nano-satellite technology has also been marked by significant advancements in subsystem technologies. Hamann et al. (2005) and Bouwmeester and Guo (2010) reviewed the technological progress in nano-satellite subsystems,[7][24] including power systems, communication modules, and attitude control systems. These advancements have been crucial in enhancing the performance and reliability of nano-satellites, enabling them to undertake more complex missions.

III. PROBLEM DEFINITION

The development of nanosatellite technology and its applications has faced a number of obstacles and challenges along the way. Some of these challenges include the limitations of miniaturization, cost reduction, and the need for a compact, lightweight, and reliable power source. These limitations have required innovative solutions and advancements to overcome the difficulties associated with nanosatellite development and operation.

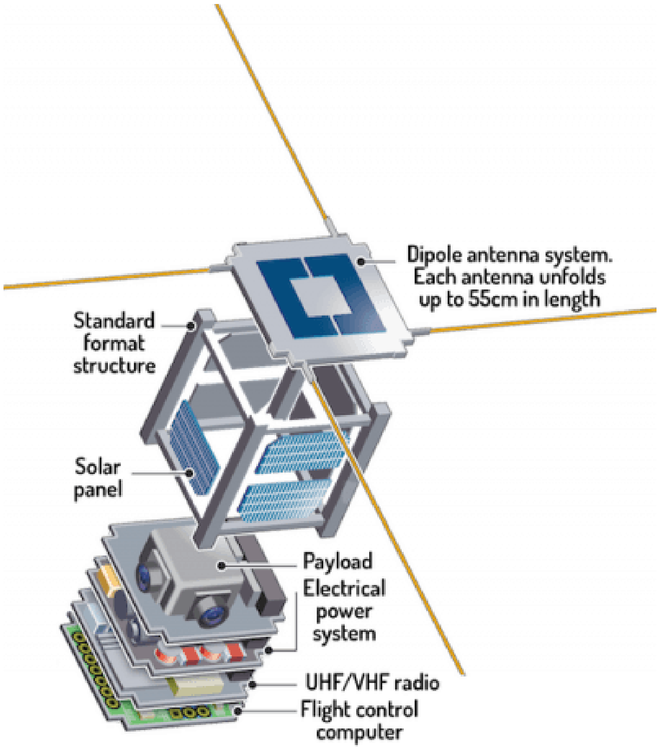


Figure 1 Basic structure of nanosatellite.

One of the major obstacles in nanosatellite development is the limitation of miniaturization. The need for smaller, lighter components has led to a number of technical challenges, including the design and fabrication of small and efficient microelectronics, as well as the development of low-cost and reliable payloads.

Another challenge in nanosatellite development is the need for cost reduction. The high cost of nanosatellites has limited their deployment and utilization, particularly in emerging countries. Researchers have been working on cost reduction strategies, such as the use of commercial off-the-shelf (COTS) components and the standardization of hardware and software.

The need for a compact, lightweight, and reliable power source is another challenge faced by the development of nanosatellites. Despite its miniaturized dimension, nanosatellites are required to transmit their radio-signal, strong enough to be picked up by the ground station's receiver, not different to the conventional-size satellites. The limited capacity of a nanosatellite's payload compartment means limited option for carrying powering devices (battery, PV panel, etc.)

The limited power capacity and availability of nanosatellites have required the development of innovative power solutions, such as the use of solar panels and energy storage devices. An overall the structure of typical nanosatellite is depicted in Figure 1.

Nanosatellite also suffers limitation in its propulsion system capacity that reduces their ability to maintain orbit. This limitation is especially a major consideration in designing nanosatellites operating in low earth orbit (LEO), a level of orbit that still has some atmospheric influence that constantly deteriorates orbit of any satellite.

IV. DESIGN PROCESS

This stage involves identifying the objectives and requirements for the nanosatellite technology survey and its applications. Nanosatellites are small satellites that are made up of several subsystems, each of which plays a critical role in the overall operation of the satellite. Some of the most important subsystems of a nanosatellite include:

1. Orbit: Satellite orbit provides a specific set of lines-of-sight or observation that a satellite can access. For this reason, the location of the satellite's object of interest on Earth determines the designed orbit of a satellite.
2. Structure: The structure of a nanosatellite provides the framework that holds all the other subsystems together and protects the satellite from the harsh conditions of space.
3. Power: The power subsystem provides the energy needed to operate the satellite and its payload. This typically includes solar panels and batteries.
4. Propulsion: The propulsion subsystem provides the means for the nanosatellite to maneuver in space and change its position or altitude.
5. Communication: The communication subsystem allows the satellite to communicate with the ground station and transmit data, such as images or scientific data, back to Earth.
6. Avionics: The avionics subsystem includes the central processing unit (CPU), memory, and other electronic components that control the operation of the satellite and its payload.
7. Payload: The payload is the specific mission equipment that the nanosatellite was designed to carry out, such as a camera, a spectrometer, or a radio frequency (RF) sensor.
8. Command and data handling (CDH): The CDH subsystem manages the satellite's data and processes the commands from the ground station.
9. Thermal control: The thermal control subsystem manages the temperature of the satellite and its components, ensuring that they are not subjected to extreme temperatures that could cause damage.

These subsystems work together to provide a complete and integrated system for the nanosatellite. The design and implementation of these subsystems is critical for the success of the mission and must be carefully considered in order to ensure that the satellite can operate effectively in space.

A. Orbit of Nanosatellite

Technically, orbit of nanosatellites is described the same way as orbit for conventional size satellites, by the same set of parameters: eccentricity, major semi-axis, longitude of ascending node, inclination, argument of periapsis, and mean anomaly.

1. Eccentricity (e).
   This parameter is the measure of orbit's shape. (Figure 2)
   a. $e = 0$ corresponds to circular orbits.
   b. $0 < e < 1$ corresponds to elliptical orbits.
   c. $e = 1$ corresponds to parabolic orbits.
   d. Any $e > 1$ corresponds to hyperbolic orbits.
2. Major semi-axis (a)
   This parameter qualitatively describes the size of the orbit. Depending on orbit's shape, it is a measure of certain geometric feature of the orbit's shape. (Figure 3)
   a. For circular orbits, orbit radius is the major semi-axis ($a = R$).
   b. For elliptical orbits, the longest diameter is the major axis ($2a$).
   c. For parabolic orbits, a is not defined.
   d. For hyperbolic orbits, a is the distance between its center to its periapsis (a point on the hyperbola that is closest to its respective focus).
3. Longitude of ascending node (Ω)
   This parameter describes the location at which the satellite's trajectory crosses Earth's equatorial plane from southern celestial sphere to northern celestial sphere. The parameter is the angular distance of this node from The First Point of Aries. (Figure 4)
4. Inclination angle (i)
   This parameter is the the angle between orbital plane to Earth's equatorial plane. Inclination angle can also refer to the angle between orbital axis to Earth's polar axis. (Figure 4)
5. Argument of periapsis (ω)
   This parameter describes the location of the orbit's periapsis, the nearest point to Earth (as opposed to apoapsis, the farthest point to Earth). This parameter is measured as the angular distance of the periapsis to the ascension node. (Figure 4)
6. True anomaly (ν)
   This parameter is the angular distance of satellite's body position to the periapsis. (Figure 4)

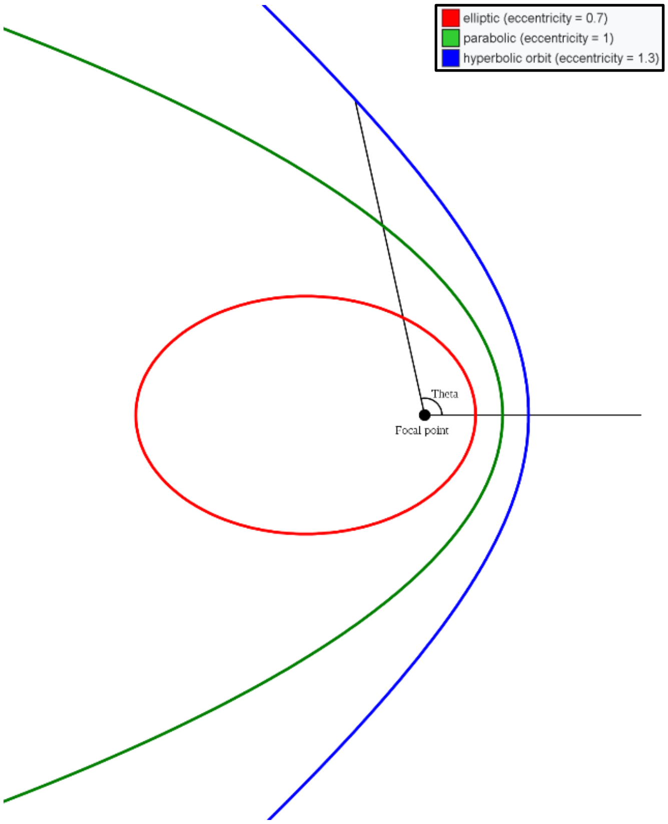
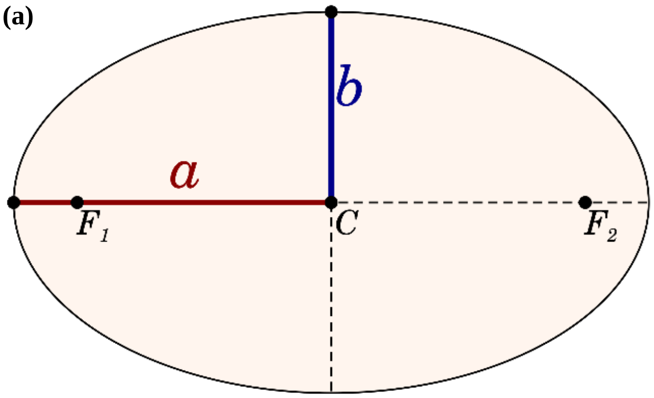


Figure 2 Orbit eccentricity (Image from wikipedia.org)



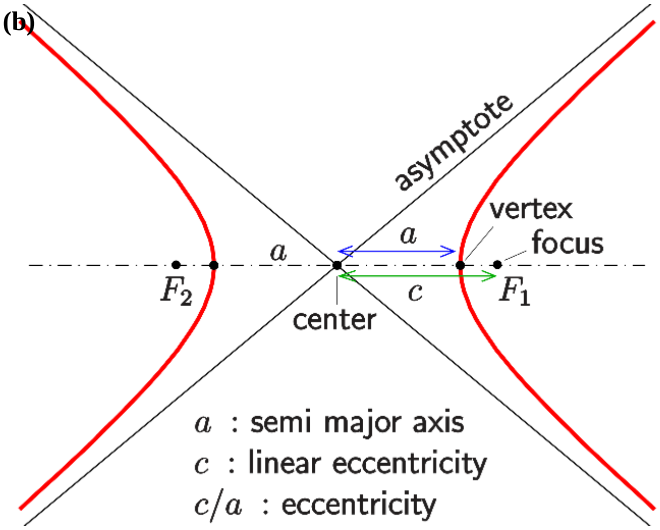


Figure 3 Major semi-axis of: elliptic orbit (a), and of hyperbolic orbit (b). (Image from wikipedia.org)

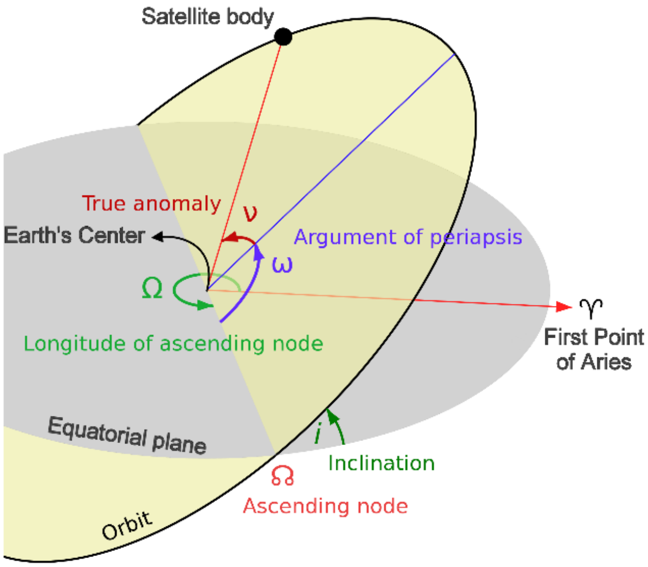


Figure 4 Parameters describing orientation of a geocentric orbit (Image from wikipedia.org)

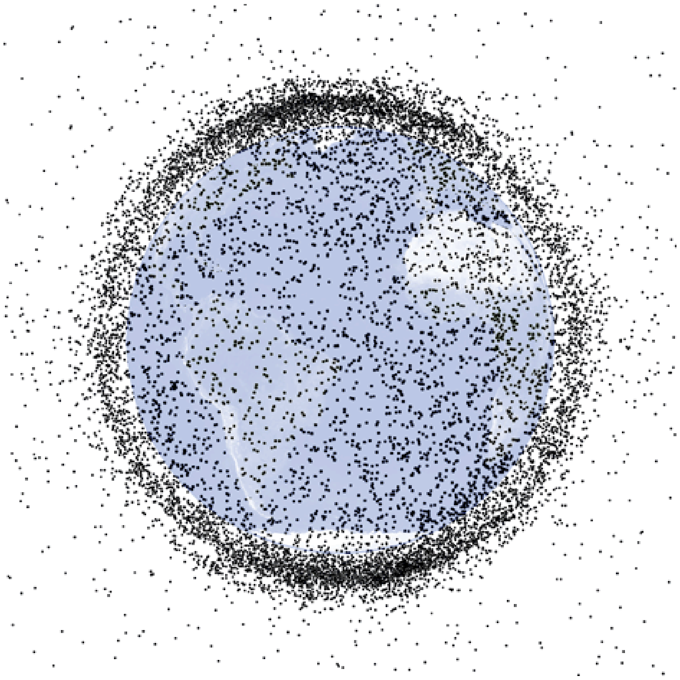


Figure 5 Orbiting objects occupying LEO region, 95% of which are space junks.[17]

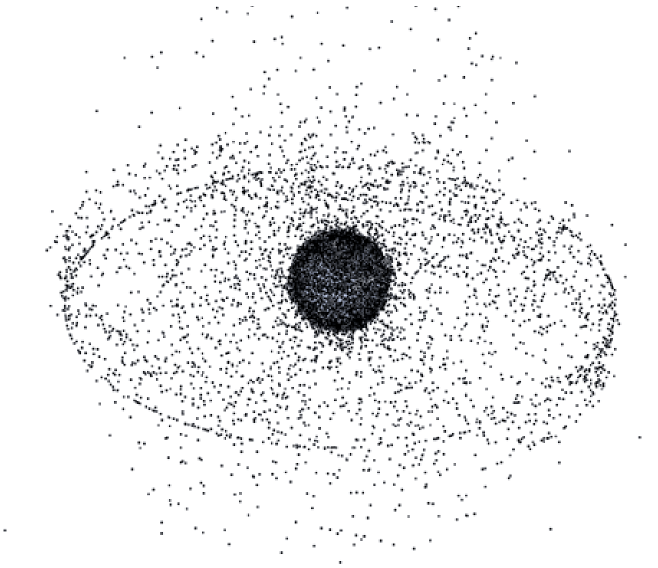


Figure 6 Orbiting objects around Earth are concentrated in LEO region, nearly obscuring Earth's surface. Objects in geostationary orbits appear like a ring around Earth.[17]

Technically, altitude is not a defining parameter of an orbit. Satellite's orbit can be classified according to its altitude, if it is circular ($e = 0$), or near circular. For non-zero eccentricity orbits, the classification breaks down since altitude varies along its angular (true anomaly) dimension. Therefore, the three classes of altitude-based classification, low Earth orbits (LEO), medium Earth orbits (MEO), and high Earth orbits (HEO), must be treated as region classification surrounding Earth instead of orbit classification: LEO region, MEO region, and HEO region.

LEO region is the space above Earth's mean sea level, ranging from 180 km to 2000 km. MEO region ranges from 2000 km to 35780 km, and HEO region ranges from 35780 km and beyond. As mentioned before, satellites in high eccentricity orbits may travel across different regions.

In LEO region, atmosphere density is non-negligence, imposing aerodynamic drag to any object passing through it as the required mean orbital velocity to maintain a stable orbit is relatively high (about 7.12 to 7.79 km/s depending on altitude). Satellites in LEO region suffer fast orbital decay due to atmospheric drag that they require periodic boost to maintain their orbit, or launching replacement satellites when the old ones de-orbits. De-orbiting satellites will eventually burn up as they fall through earth's atmosphere, and the orbits in which they reside may be repopulated by other satellites. Satellite de-orbiting is a safe way to dispose old satellites, and doing so from LEO region is the cheapest.

Placing satellites in LEO region are advantageous for many applications. Their closeness to Earth's surface means that satellites use less energy to transmit their radio signal to Earth's surface and with low latency. Excess energy can be used to provide high-bandwidth communication. A wide range of applications utilizing LEO satellites are telecommunication (e.g., Iridium system), remote sensing (deep space observation satellites, Earth observation satellites, spy satellites), orbital stations (ISS, Tiangong space station). The drawback of orbiting in LEO region is limited coverage on Earth's surface. Coverage on a full hemisphere requires several satellites. As satellite-based service providers aim to expand their service coverage, more satellites will be placed in LEO region making it a congested orbital region steadily (see Figure 5 & Figure 6).

Satellites in MEO region do not suffers aerodynamic drag as in LEO region. The natural environment of MEO region is dominated by the influence of solar radiation pressure and its interaction with Earth's magnetosphere. This makes orbit maintenance less intense for satellite in MEO region. However, the two zones of Van Allen radiation belt reside in MEO region, posing EM hazard to satellites that pass through them. Therefore, satellite that is placed in MEO region must be equipped with radiation shielding to protect it from excessive EM radiation.

Orbits in MEO region can be made to be semi-synchronous to Earth's rotation (orbital period is an integer-multiple of Earth's rotation period), which means to every point on Earth, such satellite occupies the same spot in the sky at the same time every day, providing a predictable schedule of satellite's coverage on location on Earth that is useful for navigation applications. The well-known satellite navigation systems GPS, Galileo, GLONASS, and BeiDou use MEO region. Global coverage is achieved by a constellation of satellites in many inclined orbits of different ascension nodes. For example, Galileo satellites constellation use three inclined circular orbits ($e = 0$, $a = 29599.8\,\mathrm{km}$, $i = 56°$), each spaced equally along Earth's longitude (ascending nodes (Ω) at longitude 77.632°, longitude 197.632°, and longitude 317.632°, respectively).[16] Each orbit is populated by at least 10 navigation satellites.

Also, since MEO region spans across more than 30000 km from the 2000 km level outward, MEO can be made to be sufficiently eccentric, which is useful in providing coverage focusing on one side of Earth's hemisphere. By elliptical orbit and especially high-eccentricity elliptic orbit, hemisphere in the apoapsis side receives longer coverage than the one in the periapsis side. Furthermore, eccentric orbit can be made to have high inclination, which is useful in providing coverage to high latitude area on Earth. For example, more coverage on northern hemisphere by an inclined orbit can be achieved by setting the argument of periapsis equals 90°, and for more coverage on southern hemisphere, -90°. Orbit's inclination can be up to 63° (Tundra orbit) or more (Molniya orbit).

The first utilization of Molniya orbit took place as early as the 1960s, where the then-Soviet Union launched and operated a series of satellites called Molniya. The Molniya series provide various orbital-based services such as long-range communication, broadcast relay, and photo-reconnaissance.

Since 2010, Japan's JAXA operates three satellites in a constellation called Michibiki, or Quasi-Zenith Satellite System (QZSS), a regional positioning augmentation system that augments the GPS. One of these satellites is placed in a geostationary orbit, the other two are geosynchronous Tundra orbits, providing coverage on Asia-Oceania region, with focus on the area of Japan.

However, high-eccentricity-high-inclination orbits also pose some challenges. For all high-eccentricity orbits, during satellite's travel to and from apoapsis, the distance of satellite to the ground station varies greatly which causes the strength of the downlink signal to also varies greatly, adding a layer of complexity in processing its signal. Another challenge gets added up for high-eccentricity-high-inclination orbits. In high inclination orbits, satellites will pass through the Earth's Van Allen radiation belt (Figure 7 & Figure 8), the two regions around Earth populated by streams of high-energy particles from solar and outer space which got redirected by Earth's magnetosphere and converge to Earth's magnetic poles. Satellites in such orbits require adequate shielding.

HEO region is characterized by deep space environment: no atmospheric interference, but under constant interference from space weather activities (solar and cosmic radiation activities), so radiation shielding is essential to satellites orbiting in this region.

HEO region provides unobstructed line-of-sight to Earth whole hemisphere as well as to the deep space; it is ideal to place observatories that require them. However, the cost to put satellite into HEO region, in term of launch energy, is very high, about five times more expensive than the cost to put satellite into LEO region.

B. *Structure of Nanosatellite*

The structure of a nanosatellite is one of the most critical components of the satellite, as it provides the framework that holds all the other subsystems together and protects the satellite from the harsh conditions of space. Unless it is designed to be launched using a dedicated launch vehicle, a nanosatellite's structure must also satisfy the compatibility requirement with its carrier vehicle. A widely accepted format of satellite miniaturization called CubeSat has become the norm in designing nanosatellites. This format allows rapid loading and quick exchange of nanosatellites as payload into the launch vehicle so that any launch opportunity may get utilized on short notice.

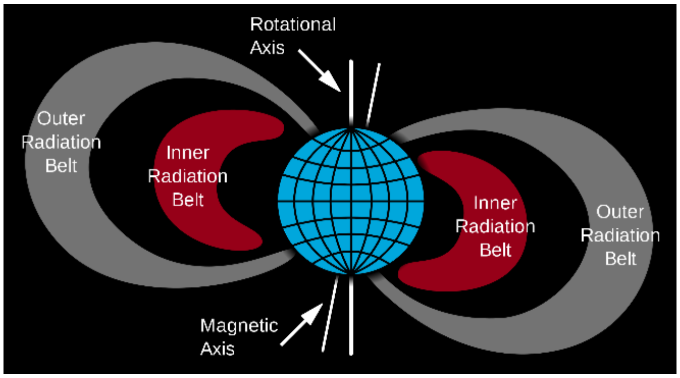


Figure 7 A cross section of Van Allen radiation belts (Image from wikipedia.org)

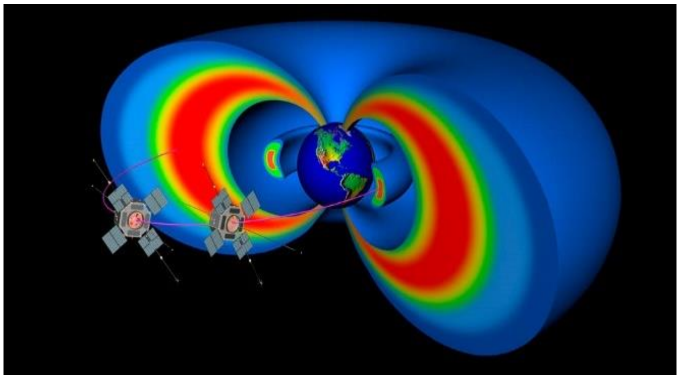


Figure 8 A cut away of 3D field that makes up the inner belt and outer belt. NASA's Van Allen Probes are depcted at the foreground.[18]

The structure is designed to be lightweight, robust, and simple, yet effective. It provides the basic framework for the CubeSat and protects it from the harsh conditions of space, allowing it to carry out its mission effectively.

A typical CubeSat structure includes the following components:

1. Frame
   The CubeSat frame is the main structural component of the satellite and provides the basic structure of the CubeSat. The frame is usually made of aluminum and consists of several panels that are connected to form a cube. The standard size of a CubeSat is measured in a unit of 10cm×10cm×11.35cm dimension and is defined as 1U (Figure 9). Each unit is designed to provide 10cm×10cm×10cm of useful volume. The unit is called form factor.
2. Payload Module
   The payload module is the part of the CubeSat that contains the mission-critical components, such as cameras, spectrometers, or other scientific instruments. The payload module is typically located in the center of the CubeSat and is surrounded by the other components of the CubeSat.

3. Power Module
   The power module provides the energy needed to operate the CubeSat and its payload. This typically includes solar panels and batteries. The power module is usually located on the top panel of the CubeSat and is responsible for generating and storing electrical energy.
4. Communication Module
   The communication module allows the CubeSat to communicate with the ground station and transmit data back to Earth. The communication module is typically located on one of the side panels of the CubeSat and includes an antenna, a transceiver, and other electronic components.
5. Attitude Determination and Control System (ADCS)
   The ADCS is responsible for maintaining the orientation of the CubeSat in space and controlling its attitude. This is important because it affects the performance of the CubeSat's solar panels and communication antenna. The ADCS typically includes magnetic torquers, reaction wheels, and sensors.
6. On-board Computer
   The on-board computer, also known as the central processing unit (CPU), is the brain of the CubeSat and controls the operation of the satellite and its payload. The CPU is typically located in the payload module and is responsible for processing commands from the ground station and managing the data generated by the CubeSat.
7. Deployable Structures
   Some nanosatellites may also include deployable structures, such as booms or antennae, which can be deployed after the CubeSat has been deployed from the launch vehicle. These structures can be used to increase the CubeSat's capability, such as by increasing its communication range.

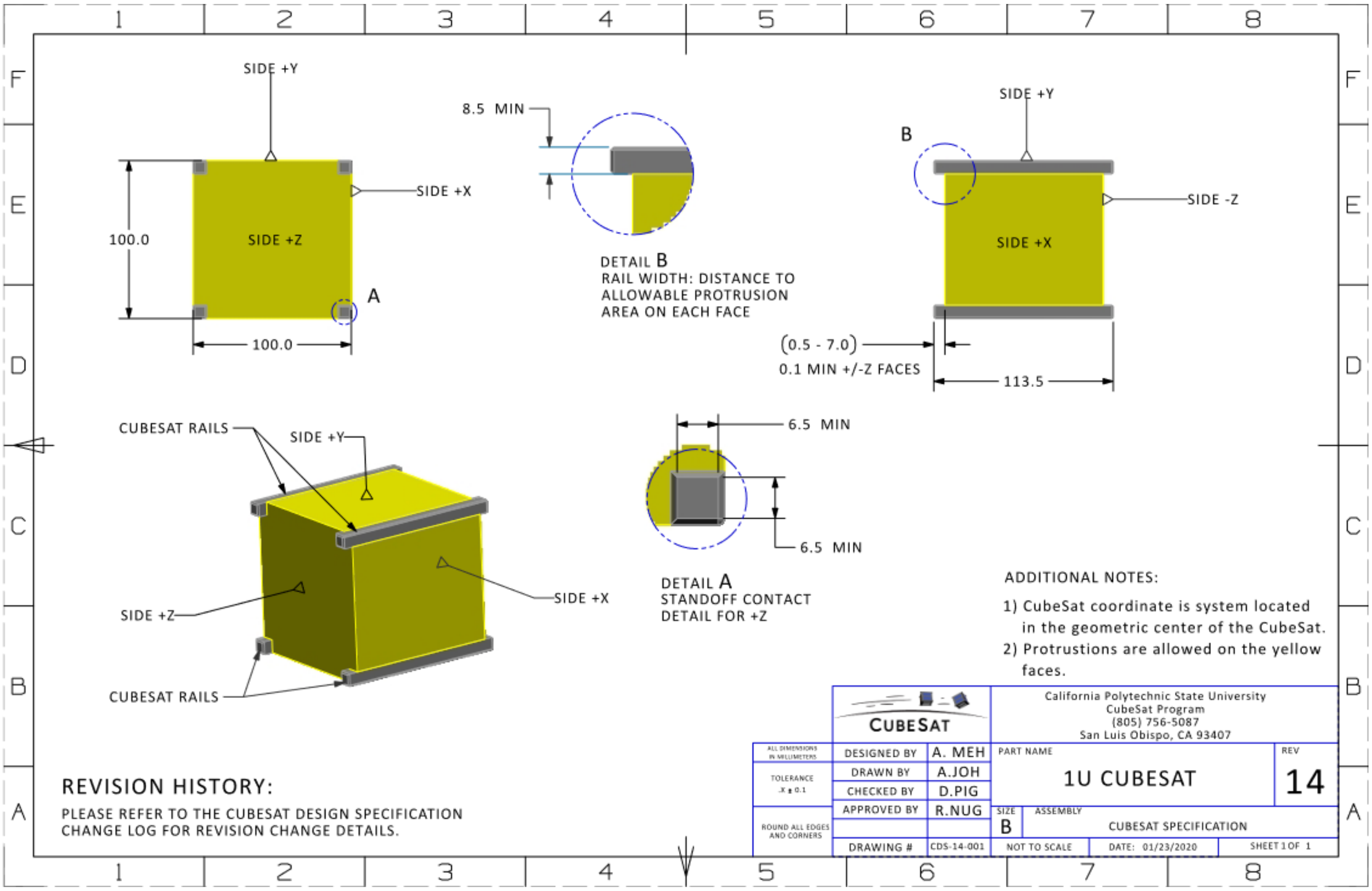


Figure 9 A technical drawing for 1U CubeSat.[15]

C. *Power Module of Nanosatellite*

The power module of a nanosatellite is an essential subsystem that provides the energy needed to operate the satellite and its payload. It is designed to be lightweight, efficient, and reliable. It provides the electrical energy needed to operate the CubeSat and its payload, and it is a critical component for the success of the mission. The design of the power module must consider the specific requirements of the mission, such as the orbit of the CubeSat, the power consumption of the payload, and the duration of the mission, to ensure that the CubeSat has enough power to complete its mission.

A typical power module includes the following components:

1. Solar Panels
   Solar panels are the primary source of power for a CubeSat. They are usually located on the top panel of the CubeSat and

convert sunlight into electrical energy. The size and number of solar panels required for a CubeSat depends on the specific requirements of the mission, such as the power consumption of the payload and the orbit of the CubeSat.

2. Batteries
   Batteries are used to store the electrical energy generated by solar panels. This energy is used to power the CubeSat and its payload during periods of time when the CubeSat is not in direct sunlight, such as during eclipses or when it is on the night side of the Earth. Batteries are also used to provide power during the initial launch and deployment of the CubeSat.
3. Power Distribution and Regulation
   The power distribution and regulation subsystem are responsible for distributing the electrical energy generated by the solar panels to the other components of the CubeSat. It also regulates the voltage and current of the electrical energy to ensure that the other components receive the correct amount of power.
4. Power Management Unit (PMU)
   The PMU is the central control unit for the power subsystem. It manages the power generated by the solar panels and stored in the batteries, and it controls the power distribution and regulation subsystem. The PMU also provides telemetry data on the power subsystem, such as the voltage and current of the batteries, to the ground station.

D. *Propulsion System Used for Nanosatellites*

Nanosatellites typically do not have propulsion systems because of their small size and weight constraints. However, there are some nanosatellites that require propulsion to carry out their missions, such as those that need to change their orbits or those that require attitude control. In these cases, nanosatellites use the following types of propulsion systems:

1. Chemical Propulsion
   Chemical propulsion systems use a chemical reaction to generate thrust and propel the CubeSat. Examples of chemical propulsion systems for nanosatellites include solid fuel rocket motors, hybrid rocket motors, and liquid fuel rocket engines. Chemical propulsion systems are relatively simple and inexpensive, but they are also limited in terms of the amount of thrust that can be generated and the duration of the burn.
2. Electric Propulsion
   Electric propulsion systems use electric fields or magnetic fields to ionize and accelerate propellant, producing a high-speed plasma plume that provides thrust. Examples of electric propulsion systems for nanosatellites include Hall effect thrusters, gridded ion thrusters, and field emission electric propulsion. Electric propulsion systems are more efficient and have longer burn durations than chemical propulsion systems, but they are also more complex and expensive.
3. Pulsed Plasma Thrusters (PPTs)
   Pulsed plasma thrusters are a type of electric propulsion system that uses brief pulses of high-energy plasma to produce thrust. PPTs are relatively simple, lightweight, and low cost, making them a popular choice for nanosatellites.
4. Reaction wheels
   These are attitude/orientation actuating devices that can produce pure angular motion.

The type of propulsion system used for a CubeSat depends on the specific requirements of the mission and the trade-offs between cost, complexity, and performance. For example, to maximize usage life, an optimized configuration of a thruster and some reaction wheels is more advantageous than those of several thrusters to perform orbital maneuver (orbit change, orbit maintenance, attitude control, etc.) since thrusters' life directly depends on the quantity of propellant that the nanosatellite can carry.

E. *Communication Module of Nanosatellites*

The communication module of a CubeSat provides reliable and efficient communication between the CubeSat and the ground station. It enables the CubeSat to receive commands and send data, and it is a critical component for the success of the mission. The design of the communication module must consider the specific requirements of the mission, such as the orbit of the CubeSat, the required data rate, and the duration of the mission, to ensure that the CubeSat has the necessary communication capabilities to complete its mission.

The communication module typically includes the following components:

1. Antennas
   Antennas are used to transmit and receive signals from the CubeSat to the ground station. nanosatellites usually have at least one antenna, but some nanosatellites may have multiple antennas to support different communication frequencies and data rates. CubeSat antennas are typically deployed after launch, and they are designed to be lightweight and compact to fit within the CubeSat's limited size and weight constraints.
2. Transceiver
   The transceiver is the main component of the communication module and is responsible for transmitting and receiving signals. The transceiver converts the data into signals that can be transmitted by the antennas, and it also demodulates signals received by the antennas into digital data that can be processed by CubeSat.
3. Radio Frequency (RF) electronics
   RF electronics are used to amplify, filter, and modulate the signals transmitted and received by CubeSat. They are also used to provide frequency conversion, if necessary, to support different communication frequencies.
4. Telemetry and Command (TM&C) subsystem
   The TM&C subsystem is responsible for controlling the CubeSat and monitoring its health and status. It communicates with the ground station to receive commands and to transmit telemetry data, such as the CubeSat's position, temperature, and power consumption.

V. RESULTS

Nanosatellites technology has both practical and non-practical applications. This study prove that nanosatellites technology have a wide range of practical applications, including :

1. Earth Observation
   Nanosatellites are equipped with sensors and cameras to observe and collect data on the earth's environment, including weather patterns, natural disasters, and climate change.
2. Scientific Research
   Nanosatellites are used for a variety of scientific research missions, including atmospheric and space weather studies, as well as experiments in areas such as materials science, biology, and physics.
3. Communication
   Nanosatellites are used for communication purposes, such as providing internet connectivity in remote areas or supporting satellite-based navigation systems.
4. Traffic Management
   Satellite equipped with ADS-B or AIS receiver can monitor aircrafts or ships, adding more coverage for air/sea traffic monitoring to the more limited terrestrial-based receiver network.
5. Networked platform
6. Remote Sensing
   Nanosatellites are equipped with sensors to monitor and collect data on the earth's environment, including agriculture, forestry, oceanography, and mineral resources, remotely.
7. Disaster Response
   Nanosatellites can be quickly deployed in response to natural disasters, such as earthquakes, volcanic eruptions, hurricanes, and tsunamis, to provide real-time images and data to support rescue and recovery efforts.
8. Military and Security
   Nanosatellites are used for military and security purposes, such as reconnaissance and surveillance missions.
9. Technology Demonstration
   Nanosatellites are used to test and demonstrate new technologies and capabilities, such as propulsion systems and communication technologies.

These are some of the practical applications of nanosatellites in use today. As the technology and capabilities of nanosatellites continue to evolve, new applications are likely to emerge in the future.

A. *Application of Nanosatellite for Earth Observation*

Nanosatellites have proven to be effective in the field of earth observation through remote sensing.

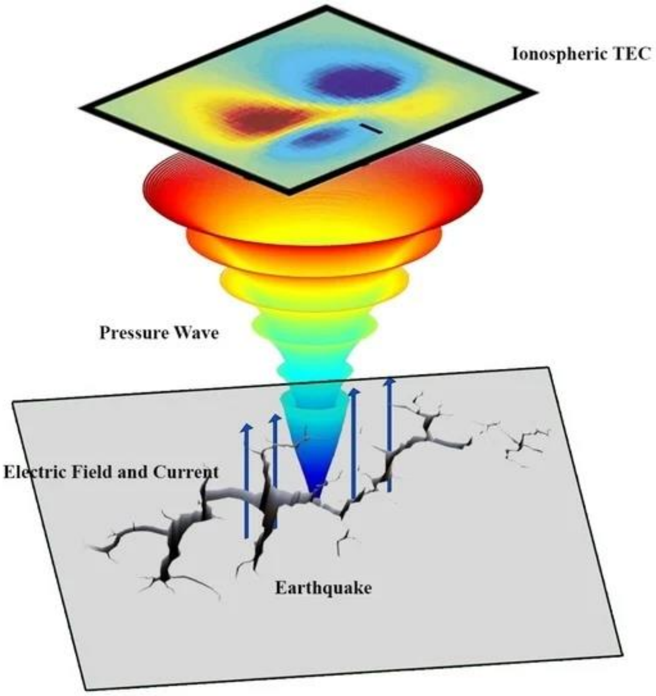


Figure 10 Nanosatellite Application for Earth Observation through Remote Sensing[21]

Most nanosatellites in this field are equipped with sensors that capture data in multiple spectral bands, providing information on the earth's surface and atmosphere. The small size and low cost of nanosatellites have allowed for the deployment of constellations, providing near-global coverage and frequent revisits. The captured data is useful for a variety of applications, including agriculture, forestry, environmental monitoring, and disaster management.

The high spatial resolution of nanosatellite-based remote sensing provides new opportunities to improve our understanding of the earth's changing landscape. This has been demonstrated in studies on land use and land cover change, vegetation health assessment, and urbanization. It is evident that nanosatellites play a crucial role in advancing the field of earth observation through remote sensing and continue to offer new possibilities for research and practical applications.

B. *Application of Nanosatellite for Scientific Research*

In recent years, the use of nanosatellites has been rapidly increasing for scientific research purposes (Figure 11). The deployment of nanosatellites has been instrumental in increasing the access to space-based data and remote sensing information, which is essential for various fields of scientific research. For instance, the use of nanosatellites is suitable for monitoring global methane gas emissions as the coresponding sensors must work at very low temperature.[22]

Figure 11 Nanosatellite Applications for Scientific Research [22][23]

The integration of nanosatellites into scientific research projects has also helped to build up the local scientific community and to promote collaboration between researchers in different regions.[23]

C. *Application of Nanosatellite for Communication*

One of the key applications of nanosatellites is in the field of communications. Nanosatellites have proven to be valuable assets in providing communication services to remote and underserved areas, including rural communities, disaster zones, and developing countries.

This study has shown that nanosatellites can offer cost-effective and efficient solutions for communication services compared to traditional satellite systems. Their small size, low cost, and quick deployment make them ideal for meeting the communication needs of remote communities and disaster zones where traditional communication infrastructure may be unavailable or damaged.

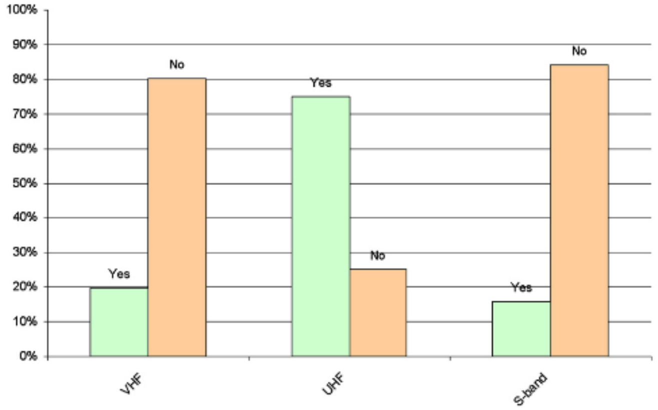


Figure 12 Used Downlink for Communication Applications[24]

Nanosatellites primarily use UHF band for downlink communication and often employ digital modulation to transmit their data at rates ranging from 1200 to 9600 bits per second (Figure 12). Some nanosatellites are capable of higher data rates, up to 80 kilobits per second. VHF and S-band are occasionally used as secondary downlink frequencies, but VHF limits the achievable data rate to 9600 bits per second, while S-band can handle data transfer rates of up to 256 kilobits per second. The uplink frequencies also display a similar distribution, but S-band is not as commonly utilized, and the available data rates are limited as the uplink is mostly utilized for sending short commands rather than large data packets.

Communication limitations between nanosatellites and the ground can mostly be attributed to the link budget rather than the radio technology itself. Despite the availability of micro-electronics that support high data rates, the scarcity of available power and limitations in ground station tracking with high gain antennas, caused by the performance of dynamic attitude control systems, restricts communication capabilities.

Additionally, nanosatellites have been used for communication purposes in the military and defense sector, providing secure and reliable communication links for military operations and intelligence gathering.

D. *Application of Nanosatellite for Traffic Management*

Air and sea traffic managements are conducted by tracking the self-identifying signals emitted by aircraft (ADS-B) and ships (AIS) during their travels. The service of aircraft or ship tracking is provided by a network of corresponding identifying signal receivers placed in ports and along strategic locations (high grounds or coastal area) and carried by satellites (of conventional size) in orbit.

A network of nanosatellites equipped with ADS-B or AIS receiver, or both, can extend the coverage of traffic management service of local traffic authorities to beyond their traditional service range, which in turn will improve traffic safety and ports' efficiency.

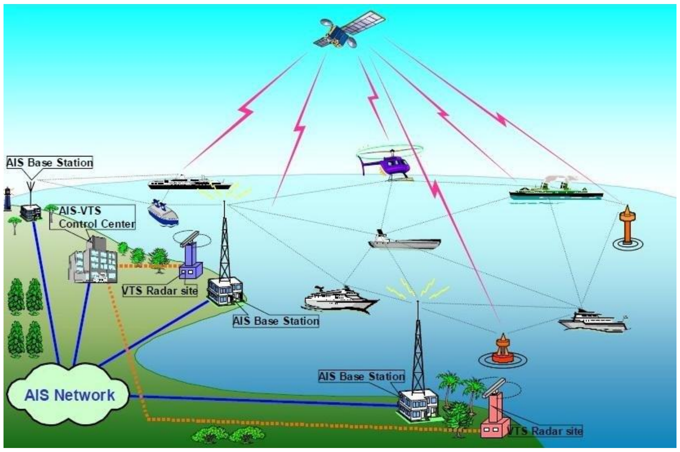


Figure 13 An AIS network
comprising terestrial and orbital assets[29]

E. *Application of Nanosatellite as Networked Platform*

This application takes advantage of multiple functionalities, roles, or capabilities provided by a group of satellites to achieve a common purpose. Such applications have been implemented using conventional size satellites, similar to each other in functionality, for various purposes such as remote sensing (the Landsat-7/EO-1 pair, the A-train costellation), navigation (Indian Regional Navigation System, Japan's Quasi-Zenith

Satellite System, China’s BeiDou, EU’s Galileo, Rusia’s GLONASS, US’s GPS), and experimental (the TechSat-21). Scaling to nanosatellite context, a group of similar nanosatellites can be placed in a certain set of complementary orbits to provide global coverage of its service (communication, monitoring, etc.).

Figure 14 The TA-1 PocketQube nanosatellite, a computational nanosatellite[30]

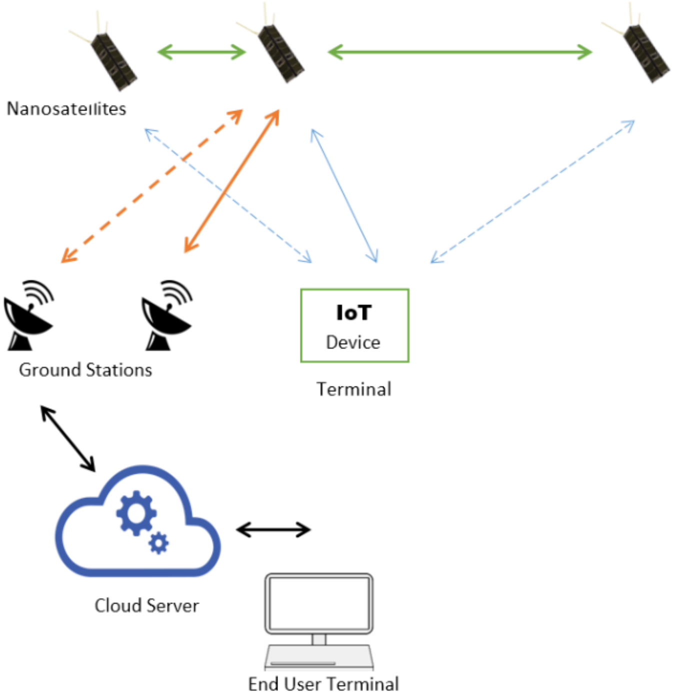


Figure 15 (Nano-) Satellite-based IoT infrastructure[31]

Furthermore, a group of nanosatellites of various functionalities can be made to cooperate to achieve certain purpose. For example, a nanosatellite can be configured to specialize in data collection tasks that feeds another that specializes in data processing task, some others specialize in downlink communication with the ground station to deliver the processed data. Also, collected data from each nanosatellite may differ in resolution types (radiometric, spectral, spatial, and temporal) depending on the type of the onboard sensor. One nanosatellite may be equipped with a sensor system, which is configured to take measurements in high radiometric resolution, to provide measurement data in high bit. Another nanosatellite may be equipped with one configured to take measurements in high spatial resolution. Another nanosatellite that specializes in data processing may fuse the data collected by those satellite into a high-bit-high-resolution image. Furthermore, when yet another nanosatellite provides data in high temporal resolution, a smooth animated time-progression data can be produced, and so on. To summarize it all, raw data from one nanosatellite may be fused with raw data from other nanosatellites to obtain a more complete (and more useful) composited data.

Such networked nanosatellites opens new opportunities to advance existing technologies such as orbital edge computing,[30] which offers new benefits compared to existing terestrial-based edge computing, and space-based data communication networks, which was previously dominated by larger satellites.[31]

VI. DISCUSSION

This study shows significant advancements in the field, providing valuable insights into the latest trends and developments, and potentials. The results indicate that nanosatellite technology has evolved rapidly over the past decade and continues to play a critical role in a wide range of industries and applications, including communication, earth observation, remote sensing, and scientific research, and transportation.

One key finding from the survey was the increasing use of nanosatellites for remote sensing and earth observation. This is due to the growing demand for high-resolution data and the ability of nanosatellites to provide this data at a lower cost compared to traditional satellite systems. The results showed that there has been a significant increase in the number of nanosatellites deployed for these applications, particularly in the areas of disaster response, agriculture, and environmental monitoring.

Another key finding was the growing use of nanosatellites for communication, particularly in areas with limited or no infrastructure. The results showed that nanosatellites are increasingly being used to provide communication services in remote and underserved areas, such as rural communities, disaster zones, and developing countries. This highlights the potential for nanosatellites to have a significant impact on global connectivity and help bridge the digital divide.

Overall, the results of the nanosatellite technology survey and its applications provide a comprehensive overview of the state of the field and highlight thopportunities and challenges facing the industry. By understanding the latest trends and developments, researchers and practitioners can better plan and invest in the future of nanosatellite technology and help support its continued growth and impact.

VII. CONCLUSION

As with other technological breakthrough, nanosatellite technology offers benefits as well as challenges. The future of nanosatellites technology is determined by our ability to make the benefits of applying this technology overcomes its challenges. Here, we list some benefits and challenges that are specifically inherent to nanosatellite's characteristics.

Benefits:

1. Cost.
   Cost benefits include manufacturing and deployment costs. Operating cost, however, depends on orbit radius (See Challenges part).
2. Rapid deployment.
   Multiple deployments of nanosatellites can be achieved through single launch flight. Each nanosatellite in that single launch can be transferred to different destination orbits.[20]
3. More benign penalty on satellite failure.
   In cases of conventional size satellites, losing satellites during launch or while in orbit (for any failure) is not rare, but every loss is expected to cause huge investment consequence due to loss in potential revenue from the service the lost satellite is expected to provide. As putting nanosatellites in orbit costs significantly less, including the cost to provide some redundancies, the risk of losing nanosatellite is much more manageable.
4. Multi-purpose functionality
   Complex applications may share the same elementary task that can be fulfilled by a single nanosatellite. For example, Earth observation satellites and spy satellites may be equipped with the same kind of sensor set since they have common elementary task: remote sensing.

Challenges:

1. Orbit altitude
   Satellites in lower orbits (including nanosatellites) have higher operating costs associated with orbit maintenance. In lower orbit environment, atmospheric gases are still present with non-negligent density that they still generate significant amount of aerodynamic drag to satellite's body so that satellites (including nanosatellites) in such orbits are expected to require more frequent orbit correction procedure. Nanosatellites in lower orbits are also expected to have much shorter lives because the amount of propellant it can carry is also inherently limited.

   Satellites in higher orbits have more overhead cost than lower orbits satellites. This overhead cost is related to the launch energy required to reach high altitude orbit. Satellites in higher orbits also have high operating cost associated with communication. As distance to the ground receiver is higher, radio signals must be stronger when transmitted. Communication also degrades due to high latency as radio signals cover more distance from the satellite to ground receiver. Low latency communication can be achieved by choosing lower orbits (and solving its associated challenges)
2. Capacity limitation.
   Equipping nanosatellites with more powerful instruments usually comes with dimension increase consequence, which unavoidably, forfeits its membership in nanosatellite category.
3. Impact on environment
   As nanosatellite technology becomes the norm in providing satellite-based services, space in orbits will become more crowded, impending future space missions. Overcrowded orbits also increase the risk of collision between satellites.

Nanosatellites have revolutionized the way we conduct research and gather information from space. These small yet mighty satellites offer numerous applications across various industries, including communication, earth observation, scientific research, and many more. Despite the challenges and obstacles in developing this technology, advancements in miniaturization and cost-effectiveness have paved the way for its widespread use and deployment. As nanosatellites continue to evolve and improve, their potential to bring about positive change and facilitate new discoveries is limitless. With the right support and investment, nanosatellites have the potential to bridge the gap between space exploration and practical applications, leading to a brighter future for all.

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