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Designing a Cubesat for Remote Sensing

Madesh D[1], Abishek B[2], Rajendraprasath B[3], Arees A[4], Gokulnath N[5], Mr. Madesh D[6]
Students, Department of Aerospace Engineering[1,2,3,4,5]
Assistant Professor, Department of Aerospace Engineering[6]
Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur, India

Abstract: There are many types of satellites used today for communication, remote sensing, Navigation, and other Military application. Cubesat reduces launch cost mainly in two fundamental ways. They don't weigh that much, which means a rocket doesn't need a lot of fuel to heft them. In most cases, they also share a rocket with a larger satellite, making it possible to get to space on the coattails of the heavier payload. In this project we are trying to design a Cubesat with the main purpose to achieve remote sensing over urban and non-reachable environmental surfaces. In comparison with a standard satellite, a cubesat of multiple numbers can achieve a wide range of information and can help to process in larger area than that of standard satellite. Cubesat can be used to experiment future technology with cost effective method of testing it with a low cost cubesat that is launched into low earth orbit to obtain experimental test results. They have the potential to give huge benefits for space research and interplanetary missions as well.

Keywords: Remote Sensing

I. INTRODUCTION

1.1 Satellite

In the context of spaceflight, a satellite is an object that has been intentionally placed into orbit. These objects are called artificial satellites to distinguish them from natural satellites such as Earth's Moon.

On 4 October 1957, the Soviet Union launched the world's first artificial satellite, Sputnik 1. Since then, about 8,900 satellites from more than 40 countries have been launched. According to a 2018 estimate, about 5,000 remained in orbit. Of those, about 1,900 were operational, while the rest had exceeded their useful lives and become space debris. Approximately 63% of operational satellites are in low Earth orbit, 6% are in medium-Earth orbit (at 20,000 km), 29% are in geostationary orbit (at 36,000 km) and the remaining 2% are in various elliptical orbits. In terms of countries with the most satellites, the United States has the most with 2,944 satellites, China is second with 499, and Russia third with 169. A few large space stations, including the International Space Station, have been launched in parts and assembled in orbit. Over a dozen space probes have been placed into orbit around other bodies and become artificial satellites of the Moon, Mercury, Venus, Mars, Jupiter, Saturn, a few asteroids, a comet and the Sun.

Satellites are used for many purposes. Among several other applications, they can be used to make star maps and maps of planetary surfaces, and also take pictures of planets they are launched into. Common types include military and civilian Earth observation satellites, communications satellites, navigation satellites, weather satellites, and space telescopes. Space stations and human spacecraft in orbit are also satellites.

Satellites can operate by themselves or as part of a larger system, a satellite formation or satellite constellation. Satellite orbits vary greatly, depending on the purpose of the satellite, and are classified in a number of ways. Well-known (overlapping) classes include low Earth orbit, polar orbit, and geostationary orbit.

A launch vehicle is a rocket that places a satellite into orbit. Usually, it lifts off from a launch pad on land. Some are launched at sea from a submarine or a mobile maritime platform, or aboard a plane (see air launch to orbit).

Satellites are usually semi-independent computer-controlled systems. Satellite subsystems attend many tasks, such as power generation, thermal control, telemetry, attitude control, scientific instrumentation, communication, etc.

1.1.1 History

A 1949 issue of Popular Science depicts the idea of an "artificial moon"

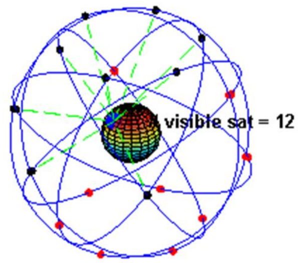

Figure 1.1 Animation depicting the orbits of GPS satellites in medium Earth orbit.

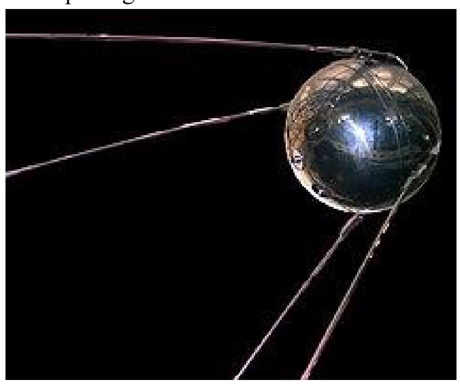

Figure 1.2 Sputnik 1: The first artificial satellite to orbit Earth.

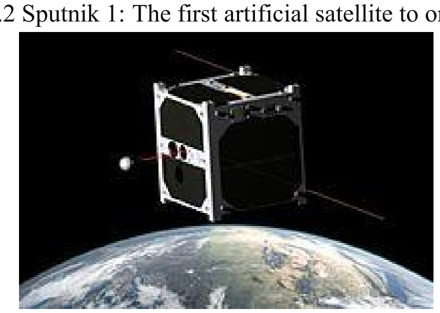

Figure1.3 1U CubeSat

ESTCube-1, developed mainly by the students from the University of Tartu, carries out a tether deployment experiment in low Earth orbit.

The first published mathematical study of the possibility of an artificial satellite was Newton's cannonball, a thought experiment by Isaac Newton to explain the motion of natural satellites, in his PhilosophiæNaturalis Principia Mathematica (1687). The first fictional depiction of a satellite being launched into orbit was a short story by Edward Everett Hale, "The Brick Moon" (1869).The idea surfaced again in Jules Verne's The Begum's Fortune (1879).

In 1903, Konstantin Tsiolkovsky (1857–1935) published Exploring Space Using Jet Propulsion Devices, which is the first academic treatise on the use of rocketry to launch spacecraft. He calculated the orbital speed required for a minimal orbit, and that a multi-stage rocket fueled by liquid propellants could achieve this.

In 1928, Herman Potočnik (1892–1929) published his sole book, The Problem of Space Travel – The Rocket Motor. He described the use of orbiting spacecraft for observation of the ground and described how the special conditions of space could be useful for scientific experiments.

In a 1945 Wireless World article, the English science fiction writer Arthur C. Clarke described in detail the possible use of communications satellites for mass communications. He suggested that three geostationary satellites would provide coverage over the entire planet.

In May 1946, the United States Air Force's Project RAND released the Preliminary Design of an Experimental World-Circling Spaceship, which stated that "A satellite vehicle with appropriate instrumentation can be expected to be one of the most potent scientific tools of the Twentieth Century."The United States had been considering launching orbital satellites since 1945 under the Bureau of Aeronautics of the United States Navy. Project RAND eventually released the report, but considered the satellite to be a tool for science, politics, and propaganda, rather than a potential military weapon.

In 1946, American theoretical astrophysicist Lyman Spitzer proposed an orbiting space telescope. In February 1954 Project RAND released "Scientific Uses for a Satellite Vehicle", written by R.R. Carhart. This expanded on potential scientific uses for satellite vehicles and was followed in June 1955 with "The Scientific Use of an Artificial Satellite", by H.K. Kallmann and W.W. Kellogg.

In the context of activities planned for the International Geophysical Year (1957–58), the White House announced on 29 July 1955 that the U.S. intended to launch satellites by the spring of 1958. This became known as Project Vanguard. On 31 July, the Soviets announced that they intended to launch a satellite by the fall of 1957.

The first artificial satellite was Sputnik 1, launched by the Soviet Union on 4 October 1957 under the Sputnik program, with Sergei Korolev as chief designer. Sputnik 1 helped to identify the density of high atmospheric layers through measurement of its orbital change and provided data on radio-signal distribution in the ionosphere. The unanticipated announcement of Sputnik 1's success

1.1.2 Tracking

Further information: Orbit determination, Satellite geodesy § Satellite tracking, and Satellite flare. Satellites can be tracked from Earth stations and also from other satellites.

1.1.3 Space Surveillance Network

The United States Space Surveillance Network (SSN), a division of the United States Strategic Command, has been tracking objects in Earth's orbit since 1957 when the Soviet Union opened the Space Age with the launch of Sputnik I. Since then, the SSN has tracked more than 26,000 objects. The SSN currently tracks more than 8,000-artificial orbiting objects. The rest have re-entered Earth's atmosphere and disintegrated, or survived re-entry and impacted the Earth. The SSN tracks objects that are 10 centimeters in diameter or larger; those now orbiting Earth range from satellites weighing several tons to pieces of spent rocket bodies weighing only 10 pounds. About seven percent are operational satellites (i.e. ~560 satellites), the rest are space debris.The United States Strategic Command is primarily interested in the active satellites, but also tracks space debris which upon reentry might otherwise be mistaken for incoming missiles.

1.1.4 Services

There are three basic categories of (non-military) satellite services:

Fixed Satellite Services

Fixed satellite services handle hundreds of billions of voice, data, and video transmission tasks across all countries and continents between certain points on the Earth's surface.

Mobile Satellite Systems

Mobile satellite systems help connect remote regions, vehicles, ships, people and aircraft to other parts of the world and/or other mobile or stationary communications units, in addition to serving as navigation systems.

Scientific Research Satellites (Commercial And Noncommercial)

Scientific research satellites provide meteorological information, land survey data (e.g. remote sensing), Amateur (HAM) Radio, and other different scientific research applications such as earth science, marine science, and atmospheric research.

Classification

Astronomical satellites are satellites used for observation of distant planets, galaxies, and other outer space objects.

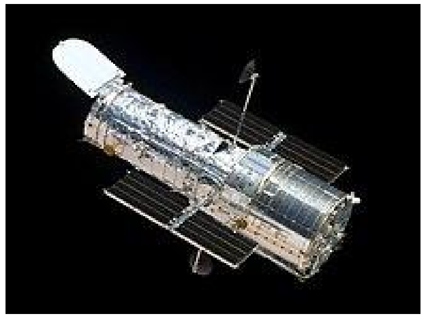

Figure1.4 The Hubble Space Telescope

Biosatellites are satellites designed to carry living organisms, generally for scientific experimentation.

Communication satellites are satellites stationed in space for the purpose of telecommunications. Modern communications satellites typically use geosynchronous orbits, Molniya orbits or Low Earth orbits.

Earth observation satellites are satellites intended for non-military uses such as environmental monitoring, meteorology, map making etc. (See especially Earth Observing System.)

Navigational satellites are satellites that use radio time signals transmitted to enable mobile receivers on the ground to determine their exact location. The relatively clear line of sight between the satellites and receivers on the ground, combined with ever-improving electronics, allows satellite navigation systems to measure location to accuracies on the order of a few meters in real time.

Killer satellites are satellites that are designed to destroy enemy warheads, satellites, and other space assets.

Crewed spacecraft (spaceships) are large satellites able to put humans into (and beyond) an orbit, and return them to Earth. (The Lunar Module of the U.S. Apollo program was an exception, in that it did not have the capability of returning human occupants to Earth.) Spacecraft including spaceplanes of reusable systems have major propulsion or landing facilities. They can be used as transport to and from the orbital stations.

Miniaturized satellites are satellites of unusually low masses and small sizes.[17] New classifications are used to categorize these satellites: minisatellite (500–1000 kg), microsatellite (below 100 kg), nanosatellite (below 10 kg).[citation needed]

Reconnaissance satellites are Earth observation satellite or communications satellite deployed for military or intelligence applications. Very little is known about the full power of these satellites, as governments who operate them usually keep information pertaining to their reconnaissance satellites classified.

Recovery satellites are satellites that provide a recovery of reconnaissance, biological, space-production and other payloads from orbit to Earth.

Space-based solar power satellites are proposed satellites that would collect energy from sunlight and transmit it for use on Earth or other places.

Space stations are artificial orbital structures that are designed for human beings to live on in outer space. A space station is distinguished from other crewed spacecraft by its lack of major propulsion or landing facilities. Space stations are designed for medium-term living in orbit, for periods of weeks, months, or even years.

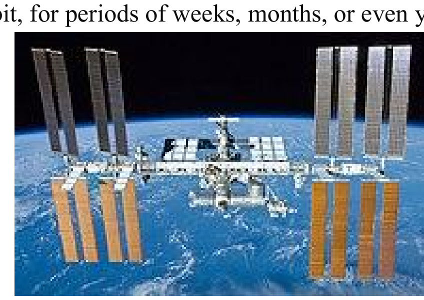

Figure1.5 International Space Station

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1.1.5 Altitude Classifications

- Low Earth orbit (LEO): Geocentric orbits ranging in altitude from 180 km – 2,000 km (1,200 mi)
- Medium Earth orbit (MEO): Geocentric orbits ranging in altitude from 2,000 km (1,200 mi) – 35,786 km (22,236 mi). Also known as an intermediate circular orbit.
- Geosynchronous orbit (GEO): Geocentric circular orbit with an altitude of 35,786 kilometres (22,236 mi). The period of the orbit equals one sidereal day, coinciding with the rotation period of the Earth. The speed is 3,075 metres per second (10,090 ft/s).
- High Earth orbit (HEO): Geocentric orbits above the altitude of geosynchronous orbit 35,786 km (22,236 mi).

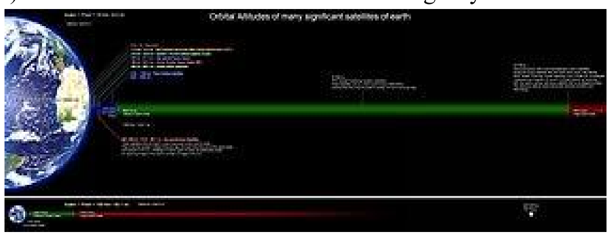

Figure1.6 Orbital Altitudes of several significant satellites of earth.

1.2 Cubesat

A CubeSat (U-class spacecraft) is a type of miniaturized satellite for space research that is made up of multiple cubic modules 10 cm (3.9 in) per side. CubeSats have a mass of no more than 1.33 kg (2.9 lb) per unit,and often use commercial off-the-shelf (COTS) components for their electronics and structure. CubeSats are put into orbit by deployers on the International Space Station, or launched as secondary payloads on a launch vehicle. As of August 2021, more than 1600 CubeSats have been launched and more than 90 have been destroyed in launch failures.

In 1999, California Polytechnic State University (Cal Poly) professor Jordi Puig-Suari and Bob Twiggs, a professor at Stanford University Space Systems Development Laboratory developed the CubeSat specifications to promote and develop the skills necessary for the design, manufacture, and testing of small satellites intended for low Earth orbit (LEO) that perform a number of scientific research functions and explore new space technologies. Academia accounted for the majority of CubeSat launches until 2013, when more than half of launches were for non-academic purposes, and by 2014 most newly deployed CubeSats were for commercial or amateur projects.

Uses typically involve experiments that can be miniaturized or serve purposes such as Earth observation or amateur radio. CubeSats are employed to demonstrate spacecraft technologies intended for small satellites or that present questionable feasibility and are unlikely to justify the cost of a larger satellite. Scientific experiments with unproven underlying theory may also find themselves aboard CubeSats because their low cost can justify higher risks. Biological research payloads have been flown on several missions, with more planned. Several missions to the Moon and beyond are planning to use CubeSats.The first CubeSats to leave Earth orbit were the two MarCO CubeSats, which did so in May 2018 on their way to Mars alongside the successful InSight mission. Some CubeSats have become countries' first-ever satellites, being launched by universities, state-owned, or private companies. The searchable Nanosatellite and CubeSat Database lists over 3,200 CubeSats that have been and are planned to be launched since 1998.

1.2.1 History

Figure1.7 1U CubeSat structure

Professors Jordi Puig-Suari of California Polytechnic State University and Bob Twiggs of Stanford University proposed the CubeSat reference design in 1999:159 with the aim of enabling graduate students to design, build, test and operate in space a spacecraft with capabilities similar to that of the first spacecraft, Sputnik. The CubeSat, as initially proposed, did not set out to become a standard; rather, it became a standard over time by a process of emergence. The first CubeSats launched in June 2003 on a Russian Eurockot, and approximately 75 CubeSats had entered orbit by 2012.

The need for such a small-factor satellite became apparent in 1998 as a result of work done at Stanford University's Space System Development Laboratory. At SSDL, students had been working on the OPAL (Orbiting Picosatellite Automatic Launcher) microsatellite since 1995. OPAL's mission to deploy daughter-ship "picosatellites" had resulted in the development of a launcher system that was "hopelessly complicated" and could only be made to work "most of the time". With the project's delays mounting, Twiggs sought DARPA funding that resulted in the redesign of the launching mechanism into a simple pusher-plate concept with the satellites held in place by a spring-loaded door.

Desiring to shorten the development cycle experienced on OPAL and inspired by the picosatellites OPAL carried, Twiggs set out to find "how much could you reduce the size and still have a practical satellite". The picosatellites on OPAL were 10.1 cm × 7.6 cm × 2.5 cm (4 in × 3 in × 1 in), a size that was not conducive to covering all sides of the spacecraft with solar cells. Inspired by a 4 in (10 cm) cubic plastic box used to display Beanie Babies in stores,[8] Twiggs first settled on the larger ten-centimeter cube as a guideline for the new (yet-to-be-named) CubeSat concept. A model of a launcher was developed for the new satellite using the same pusher-plate concept that had been used in the modified OPAL launcher. Twiggs presented the idea to Puig-Suari in the summer of 1999 and then at the Japan–U.S. Science, Technology and Space Applications Program (JUSTSAP) conference in November 1999.

The term "CubeSat" was coined to denote nanosatellites that adhere to the standards described in the CubeSat design specification. Cal Poly published the standard in an effort led by aerospace engineering professor Jordi Puig-Suari. Bob Twiggs, of the Department of Aeronautics & Astronautics at Stanford University, and currently a member of the space science faculty at Morehead State University in Kentucky, has contributed to the CubeSat community.His efforts have focused on CubeSats from educational institutions.The specification does not apply to other cube-like nanosatellites such as the NASA "MEPSI" nanosatellite, which is slightly larger than a CubeSat. GeneSat-1 was NASA's first fully automated, self-contained biological spaceflight experiment on a satellite of its size. It was also the first U.S.-launched CubeSat. This work, led by John Hines at NASA Ames Research, became the catalyst for the entire NASA CubeSat program.

The CubeSat specification accomplishes several high-level goals. The main reason for miniaturizing satellites is to reduce the cost of deployment: they are often suitable for launch in multiples, using the excess capacity of larger launch vehicles. The CubeSat design specifically minimizes risk to the rest of the launch vehicle and payloads. Encapsulation of the launcher–payload interface takes away the amount of work that would previously be required for mating a piggyback satellite with its launcher. Unification among payloads and launchers enables quick exchanges of payloads and utilization of launch opportunities on short notice.

1.2.2 Design

Figure1.8 Scientist holding a CubeSat chassis

Standard CubeSats are made up of 10 cm × 10 cm × 11.35 cm (3.94 in × 3.94 in × 4.47 in) units designed to provide 10 cm × 10 cm × 10 cm (3.9 in × 3.9 in × 3.9 in) or 1 l (0.22 imp gal; 0.26 US gal) of useful volume while weighing no more than 1.33 kg (2.9 lb) per unit. The smallest standard size is 1U, while 3U+ is composed of three units stacked lengthwise with an additional 6.4 cm (2.5 in) diameter cylinder centered on the long axis and extending 3.6 cm (1.4 in) beyond one face. The Aerospace Corporation has constructed and launched two smaller form CubeSats of 0.5U for radiation measurement and technological demonstration.A 0.3U cubesat is being tested for launch in Dec 2021.

Since nearly all CubeSats are 10 cm × 10 cm (3.9 in × 3.9 in) (regardless of length) they can all be launched and deployed using a common deployment system called a Poly-PicoSatellite Orbital Deployer (P-POD), developed and built by Cal Poly.

No electronics form factors or communications protocols are specified or required by the CubeSat Design Specification, but COTS hardware has consistently utilized certain features which many treat as standards in CubeSat electronics. Most COTS and custom designed electronics fit the form of PC/104, which was not designed for CubeSats but presents a 90 mm × 96 mm (3.5 in × 3.8 in) profile that allows most of the spacecraft's volume to be occupied. Technically, the PCI-104 form is the variant of PC/104 used and the actual pin out used does not reflect the pinout specified in the PCI-104 standard. Stack through connectors on the boards allow for simple assembly and electrical interfacing and most manufacturers of CubeSat electronics hardware hold to the same signal arrangement, but some products do not, so care must be taken to ensure consistent signal and power arrangements to prevent damage.

Care must be taken in electronics selection to ensure the devices can tolerate the radiation present. For very low Earth orbits (LEO) in which atmospheric reentry would occur in just days or weeks, radiation can largely be ignored and standard consumer grade electronics may be used. Consumer electronic devices can survive LEO radiation for that time as the chance of a single event upset (SEU) is very low. Spacecraft in a sustained low Earth orbit lasting months or years are at risk and only fly hardware designed for and tested in irradiated environments. Missions beyond low Earth orbit or which would remain in low Earth orbit for many years must use radiation-hardened devices. Further considerations are made for operation in high vacuum due to the effects of sublimation, outgassing, and metal whiskers, which may result in mission failure.

Different classifications are used to categorize such miniature satellites based on mass.[citation needed] 1U CubeSats belong to the genre of picosatellites.
Minisatellite (100–500 kg (220–1,100 lb))
Microsatellite (10–100 kg (22–220 lb))
Nanosatellite (1–10 kg (2.2–22.0 lb))
Picosatellite (0.1–1 kg (0.22–2.20 lb))
Femtosatellite (0.01–0.1 kg (0.022–0.220 lb))

In recent years larger CubeSat platforms have been developed, most commonly 6U (10 cm × 20 cm × 30 cm (3.9 in × 7.9 in × 11.8 in) or 12 cm × 24 cm × 36 cm (4.7 in × 9.4 in × 14.2 in)[25]) and 12U (20 cm × 20 cm × 30 cm (7.9 in × 7.9 in × 11.8 in) or 24 cm × 24 cm × 36 cm (9.4 in × 9.4 in × 14.2 in)), to extend the capabilities of CubeSats beyond academic and technology validation applications and into more complex science and national defense goals.

In 2014 two 6U Perseus-M CubeSats were launched for maritime surveillance, the largest yet at the time. The 2018 launch of the InSight lander to Mars included two 6U CubeSats called Mars Cube One (MarCO).

Most CubeSats carry one or two scientific instruments as their primary mission payload.

1.2.3 Structure

The number of joined units classifies the size of CubeSats and according to the CubeSat Design Specification are scalable along only one axis to fit the forms of 0.5U, 1U, 1.5U, 2U, or 3U. All the standard sizes of CubeSat have been built and launched, and represent the form factors for nearly all launched CubeSats as of 2015. Materials used in the structure must feature the same coefficient of thermal expansion as the deployer to prevent jamming. Specifically, allowed materials are four aluminum alloys: 7075, 6061, 5005, and 5052. Aluminum used on the structure which contacts the P-POD must be anodized to prevent cold welding, and other materials may be used for the structure if a waiver is obtained.Beyond cold welding, further consideration is put into material selection as not all materials can be used in vacuums. Structures often feature soft dampers at each end, typically made of rubber, to lessen the effects of impacting other CubeSats in the P-POD.

Protrusions beyond the maximum dimensions are allowed by the standard specification, to a maximum of 6.5 mm (0.26 in) beyond each side. Any protrusions may not interfere with the deployment rails and are typically occupied by antennas and solar panels. In Revision 13 of the CubeSat Design Specification an extra available volume was defined for use on 3U projects. The additional volume is made possible by space typically wasted in the P-POD Mk III's spring mechanism. 3U CubeSats which utilize the space are designated 3U+ and may place components in a cylindrical volume centered on one end of the CubeSat. The cylindrical space has a maximum diameter of 6.4 cm (2.5 in) and a height no greater than 3.6 cm (1.4 in) while not allowing for any increase in mass beyond the 3U's maximum of 4 kg (8.8 lb). Propulsion systems and antennas are the most common components that might require the additional volume, though the payload sometimes extends into this volume. Deviations from the dimension and mass requirements can be waived following application and negotiation with the launch service provider.

CubeSat structures do not have all the same strength concerns as larger satellites do, as they have the added benefit of the deployer supporting them structurally during launch. Still, some CubeSats will undergo vibration analysis or structural analysis to ensure that components unsupported by the P-POD remain structurally sound throughout the launch.Despite rarely undergoing the analysis that larger satellites do, CubeSats rarely fail due to mechanical issues.

1.2.4 Computing

Like larger satellites, CubeSats often feature multiple computers handling different tasks in parallel including the attitude control (orientation), power management, payload operation, and primary control tasks. COTS attitude-control systems typically include their own computer, as do the power management systems. Payloads must be able to interface with the primary computer to be useful, which sometimes requires the use of another small computer. This may be due to limitations in the primary computer's ability to control the payload with limited communication protocols, to prevent overloading the primary computer with raw data handling, or to ensure payload's operation continues uninterrupted by the spacecraft's other computing needs such as communication. Still, the primary computer may be used for payload related tasks, which might include image processing, data analysis, and data compression. Tasks which the primary computer typically handles include the delegation of tasks to the other computers, attitude control, calculations for orbital maneuvers, scheduling, and activation of active thermal control components. CubeSat computers are highly susceptible to radiation and builders will take special steps to ensure proper operation in the high radiation of space, such as the use of ECC RAM. Some satellites may incorporate redundancy by implementing multiple primary computers, this could be done on valuable missions to lessen the risk of mission failure. Consumer smartphones have been used for computing in some CubeSats, such as NASA's PhoneSats.

1.2.5 Attitude Control

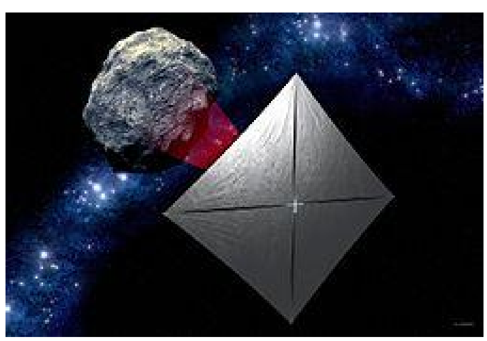

Figure 1.9 Near-Earth Asteroid Scout concept: a controllable solar sail CubeSat

Attitude control (orientation) for CubeSats relies on miniaturizing technology without significant performance degradation. Tumbling typically occurs as soon as a CubeSat is deployed, due to asymmetric deployment forces and bumping with other CubeSats. Some CubeSats operate normally while tumbling, but those that require pointing in a certain direction or cannot operate safely while spinning, must be detumbled. Systems that perform attitude determination

and control include reaction wheels, magnetorquers, thrusters, star trackers, Sun sensors, Earth sensors, angular rate sensors, and GPS receivers and antennas. Combinations of these systems are typically seen in order to take each method's advantages and mitigate their shortcomings. Reaction wheels are commonly utilized for their ability to impart relatively large moments for any given energy input, but reaction wheel's utility is limited due to saturation, the point at which a wheel cannot spin faster. Examples of CubeSat reaction wheels include the Maryland Aerospace MAI-101 and the Sinclair Interplanetary RW-0.03-4. Reaction wheels can be desaturated with the use of thrusters or magnetorquers. Thrusters can provide large moments by imparting a couple on the spacecraft but inefficiencies in small propulsion systems cause thrusters to run out of fuel rapidly. Commonly found on nearly all CubeSats are magnetorquers which run electricity through a solenoid to take advantage of Earth's magnetic field to produce a turning moment. Attitude-control modules and solar panels typically feature built-in magnetorquers. For CubeSats that only need to detumble, no attitude determination method beyond an angular rate sensor or electronic gyroscope is necessary.
Pointing in a specific direction is necessary for Earth observation, orbital maneuvers, maximizing solar power, and some scientific instruments. Directional pointing accuracy can be achieved by sensing Earth and its horizon, the Sun, or specific stars. Sinclair Interplanetary's SS-411 sun sensor and ST-16 star tracker both have applications for CubeSats and have flight heritage. Pumpkin's Colony I Bus uses an aerodynamic wing for passive attitude stabilization. Determination of a CubeSat's location can be done through the use of on-board GPS, which is relatively expensive for a CubeSat, or by relaying radar tracking data to the craft from Earth-based tracking systems.

1.2.6 Propulsion

CubeSat propulsion has made rapid advancements in the following technologies: cold gas, chemical propulsion, electric propulsion, and solar sails. The biggest challenge with CubeSat propulsion is preventing risk to the launch vehicle and its primary payload while still providing significant capability. Components and methods that are commonly used in larger satellites are disallowed or limited, and the CubeSat Design Specification (CDS) requires a waiver for pressurization above 1.2 atm (120 kPa), over 100 Wh of stored chemical energy, and hazardous materials.Those restrictions pose great challenges for CubeSat propulsion systems, as typical space propulsion systems utilize combinations of high pressures, high energy densities, and hazardous materials. Beyond the restrictions set forth by launch service providers, various technical challenges further reduce the usefulness of CubeSat propulsion. Gimbaled thrust cannot be used in small engines due to the complexity of gimbaling mechanisms, thrust vectoring must instead be achieved by thrusting asymmetrically in multiple-nozzle propulsion systems or by changing the center of mass relative to the CubeSat's geometry with actuated components.Small motors may also not have room for throttling methods that allow smaller than fully on thrust, which is important for precision maneuvers such as rendezvous.[38] CubeSats which require longer life also benefit from propulsion systems, when used for orbit keeping a propulsion system can slow orbital decay.

Cold Gas Thrusters

A cold gas thruster typically stores inert gas, such as nitrogen, in a pressurized tank and releases the gas through a nozzle to produce thrust. Operation is handled by just a single valve in most systems, which makes cold gas the simplest useful propulsion technology. Cold gas propulsion systems can be very safe since the gases used do not have to be volatile or corrosive, though some systems opt to feature dangerous gases such as sulfur dioxide. This ability to use inert gases is highly advantageous to CubeSats as they are usually restricted from hazardous materials. Unfortunately, only low performance can be achieved with them, preventing high impulse maneuvers even in low mass CubeSats. Due to this low performance, their use in CubeSats for main propulsion is limited and designers choose higher efficiency systems with only minor increases in complexity. Cold gas systems more often see use in CubeSat attitude control.

Chemical Propulsion

Chemical propulsion systems use a chemical reaction to produce a high-pressure, high-temperature gas that accelerates out of a nozzle. Chemical propellant can be liquid, solid or a hybrid of both. Liquid propellants can be a monopropellant passed through a catalyst, or bipropellant which combusts an oxidizer and a fuel. The benefits of monopropellants are relatively low-complexity/high-thrust output, low power requirements, and high reliability. Monopropellant motors tend to have high thrust while remaining comparatively simple, which also provides high reliability. These motors are practical for CubeSats due to their low power requirements and because their simplicity allows them to be very small. Small hydrazine fueled motors have been developed, but may require a waiver to fly due to restrictions on hazardous chemicals set forth in the CubeSat Design Specification.Safer chemical propellants which would not require hazardous chemical waivers are being developed, such as AF-M315 (hydroxylammonium nitrate) for which motors are being or have been designed. A "Water Electrolysis Thruster" is technically a chemical propulsion system, as it burns hydrogen and oxygen which it generates by on-orbit electrolysis of water.

Electric Propulsion

Figure1.10 Busek's BIT-3 ion thruster proposed for NASA's Lunar IceCube mission

CubeSat electric propulsion typically uses electric energy to accelerate propellant to high speed, which results in high specific impulse. Many of these technologies can be made small enough for use in nanosatellites, and several methods are in development. Types of electric propulsion currently being designed for use in CubeSats include Hall-effect thrusters, ion thrusters, pulsed plasma thrusters, electrospray thrusters, and resistojets. Several notable CubeSat missions plan to use electric propulsion, such as NASA's Lunar IceCube. The high efficiency associated with electric propulsion could allow CubeSats to propel themselves to Mars. Electric propulsion systems are disadvantaged in their use of power, which requires the CubeSat to have larger solar cells, more complicated power distribution, and often larger batteries. Furthermore, many electric propulsion methods may still require pressurized tanks to store propellant, which is restricted by the CubeSat Design Specification.

The ESTCube-1 used an electric solar-wind sail, which relies on an electromagnetic field to act as a sail instead of a solid material. This technology used an electric field to deflect protons from solar wind to produce thrust. It is similar to an electrodynamic tether in that the craft only needs to supply electricity to operate.

Solar Sail

Solar sails (also called light sails or photon sails) are a form of spacecraft propulsion using the radiation pressure (also called solar pressure) from stars to push large ultra-thin mirrors to high speeds, requiring no propellant. Force from a solar sail scales with the sail's area, this makes sails well suited for use in CubeSats as their small mass results in the greater acceleration for a given solar sail's area. However, solar sails still need to be quite large compared to the satellite, which means useful solar sails must be deployed, adding mechanical complexity and a potential source of failure. This propulsion method is the only one not plagued with restrictions set by the CubeSat Design Specification, as it does not require high pressures, hazardous materials, or significant chemical energy. Few CubeSats have employed a solar sail as its main propulsion and stability in deep space, including the 3U NanoSail-D2 launched in 2010, and the LightSail-1 in May 2015.

CubeSail is currently testing in orbit a 260-metre (850 ft)-long, 20 m2 (220 sq ft) solar sail ribbon extended between two CubeSats, that will inform the design for a much larger concept called UltraSail heliogyro. LightSail-2 successfully deployed on a Falcon Heavy rocket in 2019,[51][52] while at least one CubeSat that plan to launch on the Space Launch System's first flight (Artemis 1) in 2021 is set to use a solar sail: the Near-Earth Asteroid Scout (NEA Scout).

1.2.7 Power

CubeSats use solar cells to convert solar light to electricity that is then stored in rechargeable lithium-ion batteries that provide power during eclipse as well as during peak load times. These satellites have a limited surface area on their external walls for solar cells assembly, and has to be effectively shared with other parts, such as antennas, optical sensors, camera lens, propulsion systems, and access ports. Lithium-ion batteries feature high energy-to-mass ratios, making them well suited to use on mass-restricted spacecraft. Battery charging and discharging is typically handled by a dedicated electrical power system (EPS). Batteries sometimes feature heaters to prevent the battery from reaching dangerously low temperatures which might cause battery and mission failure.

Figure1.11 Winglet solar panels increase surface area for power generation

The rate at which the batteries decay depends on the number of cycles for which they are charged and discharged, as well as the depth of each discharge: the greater the average depth of discharge, the faster a battery degrades. For LEO missions, the number of cycles of discharge can be expected to be on the order of several hundred.

If it happens that the spacecraft is launched into a sun-synchronous orbit, the amount of eclipse time will dwindle, allowing fewer interruptions of continuous solar irradiation for the PV cells and thus reducing the battery capacity requirements. In LEO sun-synchronous orbits, however, the spacecraft will not always experience sunlight, and so depending on the time of year, the spacecraft may need to gain altitude to again be in the line of sight to the sun.[citation needed] Due to size and weight constraints, common CubeSats flying in LEO with body-mounted solar panels have generated less than 10 W. Missions with higher power requirements can make use of attitude control to ensure the solar panels remain in their most effective orientation toward the Sun, and further power needs can be met through the addition and orientation of deployed solar arrays. Recent innovations include additional spring-loaded solar arrays that deploy as soon as the satellite is released, as well as arrays that feature thermal knife mechanisms that would deploy the panels when commanded. CubeSats may not be powered between launch and deployment, and must feature a remove-before-flight pin which cuts all power to prevent operation during loading into the P-POD. Additionally, a deployment switch is actuated while the craft is loaded into a P-POD, cutting power to the spacecraft and is deactivated after exiting the P-POD.

1.2.8 Telecommunications

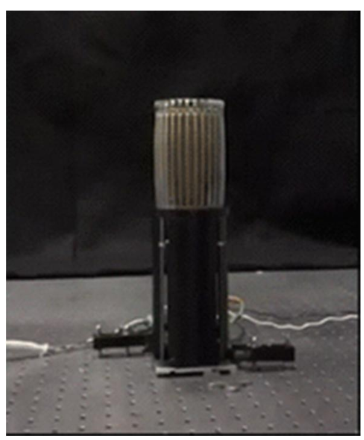

Figure1.12 Deployable high-gain mesh reflector antenna operating at Ka-band for the Radar in a Cubesat (RaInCube).

The low cost of CubeSats has enabled unprecedented access to space for smaller institutions and organizations but, for most CubeSat forms, the range and available power is limited to about 2W for its communications antennae.

Because of tumbling and low power range, radio-communications are a challenge. Many CubeSats use an omnidirectional monopole or dipole antenna built with commercial measuring tape. For more demanding needs, some companies offer high-gain antennae for CubeSats, but their deployment and pointing systems are significantly more complex. For example, MIT and JPL are developing an inflatable dish antenna with a useful range to the Moon but appears to be poorly efficient. JPL has successfully developed X-band and Ka-band high-gain antennas for MarCO and Radar in a CubeSat (RaInCube) missions.

Antennas

Traditionally, Low Earth Orbit Cubesats use antennas for communication purpose at UHF and S-band. To venture farther in the solar system, larger antennas compatible with the Deep Space Network (X-band and Ka-band) are required. JPL's engineers developed several deployable high-gain antennas compatible with 6U-class CubeSats for MarCO[60][64] and Near-Earth Asteroid Scout.[65] JPL's engineers have also developed a 0.5 m (1 ft 8 in) mesh reflector antenna operating at Ka-band and compatible with the DSN[60][64][66] that folds in a 1.5U stowage volume. For MarCO, JPL's antenna engineers designed a Folded Panel Reflectarray (FPR)[67] to fit on a 6U Cubesat bus and supports X-band Mars-to-Earth telecommunications at 8kbit/s at 1AU.

Thermal Management

Different CubeSat components possess different acceptable temperature ranges, beyond which they may become temporarily or permanently inoperable. Satellites in orbit are heated by radiative heat emitted from the Sun directly and reflected off Earth, as well as heat generated by the craft's components. CubeSats must also cool by radiating heat either into space or into the cooler Earth's surface, if it is cooler than the spacecraft. All of these radiative heat sources and sinks are rather constant and very predictable, so long as the CubeSat's orbit and eclipse time are known.

Components used to ensure the temperature requirements are met in CubeSats include multi-layer insulation and heaters or the battery. Other spacecraft thermal control techniques in small satellites include specific component placement based on expected thermal output of those components and, rarely, deployed thermal devices such as louvers. Analysis and simulation of the spacecraft's thermal model is an important determining factor in applying thermal management components and techniques. CubeSats with special thermal concerns, often associated with certain deployment mechanisms and payloads, may be tested in a thermal vacuum chamber before launch. Such testing provides a larger degree of assurance than full-sized satellites can receive, since CubeSats are small enough to fit inside of a thermal vacuum chamber in their entirety. Temperature sensors are typically placed on different CubeSat components so that action may be taken to avoid dangerous temperature ranges, such as reorienting the craft in order to avoid or introduce direct thermal radiation to a specific part, thereby allowing it to cool or heat.

1.2.9 Costs

CubeSat forms a cost-effective independent means of getting a payload into orbit.[14] After delays from low-cost launchers such as Interorbital Systems,[68] launch prices have been about $100,000 per unit, but newer operators are offering lower pricing. A typical price to launch a 1U cubesat with a full service contract (including end-to-end integration, licensing, transportation etc.) was about $60,000 in 2021.

Some CubeSats have complicated components or instruments, such as LightSail-1, that pushes their construction cost into the millions of dollars, but a basic 1U CubeSat can cost about $50,000 to constructso CubeSats are a viable option for some schools and universities; as well as small businesses to develop CubeSats for commercial purposes.

Notable Past Missions

Figure 1.13 NanoRacks CubeSats being launched from the NanoRacksCubeSatDeployer on the ISS on February 25, 2014.

The Nanosatellite&Cubesat Database lists almost 2,000 CubeSats that have been launched since 1998. One of the earliest CubeSat launches was on 30 June 2003 from Plesetsk, Russia, with Eurockot Launch Services's Multiple Orbit Mission. The CubeSats were injected into a Sun-synchronous orbit and included the Danish AAU CubeSat and DTUSat, the Japanese XI-IV and CUTE-1, the Canadian Can X-1, and the US Quakesat.

On February 13, 2012, three PPODs deployers containing seven CubeSats were placed into orbit along with the Lares satellite aboard a Vega rocket launched from French Guiana. The CubeSats launched were e-st@r Space (Politecnico di Torino, Italy), Goliat (University of Bucarest, Romania), MaSat-1 (Budapest University of Technology and Economics, Hungary), PW-Sat (Warsaw University of Technology, Poland), Robusta (University of Montpellier 2, France), UniCubeSat-GG (University of Rome La Sapienza, Italy), and XaTcobeo (University of Vigo and INTA, Spain). The CubeSats were launched in the framework of the "Vega Maiden Flight" opportunity of the European Space Agency.

On September 13, 2012, eleven CubeSats were launched from eight P-PODs, as part of the "OutSat" secondary payload aboard a United Launch Alliance Atlas V rocket. This was the largest number of CubeSats (and largest volume of 24U) successfully placed to orbit on a single launch, this was made possible by use of the new NPS CubeSat Launcher system (NPSCuL) developed at the Naval Postgraduate School (NPS). The following CubeSats were placed in orbit: SMDC-ONE 2.2 (Baker), SMDC-ONE 2.1 (Able), AeroCube 4.0(x3), Aeneas, CSSWE, CP5, CXBN, CINEMA, and Re (STARE).

Five CubeSats (Raiko, Niwaka, We-Wish, TechEdSat, F-1) were placed into orbit from the International Space Station on October 4, 2012, as a technology demonstration of small satellite deployment from the ISS. They were launched and delivered to ISS as a cargo of Kounotori 3, and an ISS astronaut prepared the deployment mechanism attached to Japanese Experiment Module's robotic arm.

Four CubeSats were deployed from the Cygnus Mass Simulator, which was launched April 21, 2013 on the maiden flight of Orbital Sciences' Antares rocket. Three of them are 1U PhoneSats built by NASA's Ames Research Center to demonstrate the use of smart phones as avionics in CubeSats. The fourth was a 3U satellite, called Dove-1, built by Planet Labs.

On April 26, 2013 NEE-01 Pegaso was launched and was the first cubesat able to transmit live video from orbit, also the first 1U cubesat to achieve more than 100 Watts of power as installed capacity, later on November same year NEE-02 Krysaor also transmitted live video from orbit, both cubesats were built by the Ecuadorian Space Agency

A total of thirty-three CubeSats were deployed from the ISS on February 11, 2014. Of those thirty-three, twenty-eight were part of the Flock-1 constellation of Earth-imaging CubeSats. Of the other five, two are from other US-based companies, two from Lithuania, and one from Peru.

The LightSail-1 is a 3U CubeSat prototype propelled by a solar sail. It was launched on 20 May 2015 from Florida. Its four sails are made of very thin Mylar and have a total area of 32 m^2 (340 sq ft). This test will allow a full checkout of the satellite's systems in advance of the main 2016 mission.

On October 5, 2015, AAUSAT5 (Aalborg University, Denmark), was deployed from the ISS. launched in the framework of the "Fly Your Satellite!" programme of the European Space Agency.

The Miniature X-ray Solar Spectrometer CubeSat is a 3U launched to the International Space Station on 6 December 2015 from where it was deployed on 16 May 2016. It is the first mission launched in the NASA Science Mission Directorate CubeSat Integration Panel, which is focused on doing science with CubeSats. As of 12 July 2016, the minimum mission success criteria (one month of science observations) has been met, but the spacecraft continues to perform nominally and observations continue.

Three CubeSats were launched on April 25, 2016, together with Sentinel-1B on a Soyuz rocket VS14 launched from Kourou, French Guiana. The satellites were: AAUSAT4 (Aalborg University, Denmark), e-st@r-II (Politecnico di Torino, Italy) and OUFTI-1 (Université de Liège, Belgium). The CubeSats were launched in the framework of the "Fly Your Satellite!" programme of the European Space Agency.

On February 15, 2017, Indian Space Research Organisation (ISRO) set record with the launch of 104 satellites on a single rocket. The launch of PSLV-C37 in a single payload, including the Cartosat-2 series and 103 co-passenger satellites, together weighed over 650 kg (1,430 lb). Of the 104 satellites, all but three were CubeSats. Of the 101 nano satellites, 96 were from the United States and one each from Israel, Kazakhstan, the Netherlands, Switzerland and the United Arab Emirates.

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018 Insight Mission: Marco Cubesats

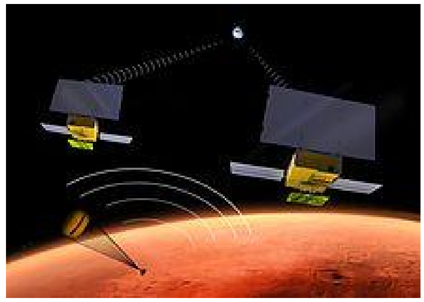


Figure1.14 An artist's rendering of MarCO A and B during the descent of InSight

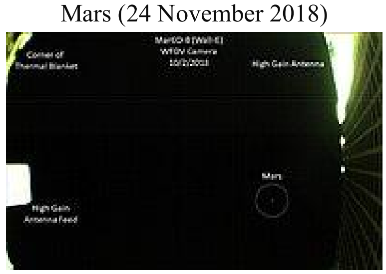
The May 2018 launch of the InSight stationary Mars lander included two CubeSats to flyby Mars to provide additional relay communications from InSight to Earth during entry and landing. This is the first flight of CubeSats in deep space. The mission CubeSat technology is called Mars Cube One (MarCO), each one is a six-unit CubeSat, 14.4 in × 9.5 in × 4.6 in (37 cm × 24 cm × 12 cm). MarCo is an experiment, but not necessary for the InSight mission, to add relay communications to space missions in important time durations, in this case from the time of InSight atmospheric entry to its landing.

MarCO launched in May 2018 with the InSight lander, separated after launch and then traveled in their own trajectories to Mars. After separation, both MarCO spacecraft deployed two radio antennas and two solar panels. The high-gain, X band antenna is a flat panel to direct radio waves. MarCO navigated to Mars independently from the InSight lander, making their own course adjustments on the flight.

During InSight's entry, descent and landing (EDL) in November 2018, the lander transmitted telemetry in the UHF radio band to NASA's Mars Reconnaissance Orbiter (MRO) flying overhead. MRO forwarded EDL information to Earth using a radio frequency in the X band, but cannot simultaneously receive information in one band if transmitting on another. Confirmation of a successful landing could be received on Earth several hours after, so MarCO was a technology demonstration of real-time telemetry during the landing.

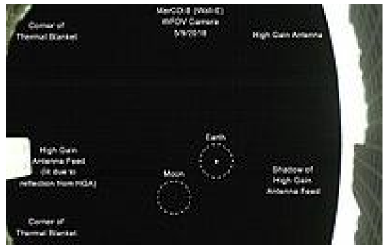
Views from MarCO

Mars (24 November 2018)



Mars (2 October 2018)

DOI: 10.48175/568



Earth and Moon (9 May 2018)

Cubesat Programs


Figure1.15 NanoRacks

Cubesat Launch Initiative

NASA's CubeSat Launch Initiative, created in 2010, provides CubeSat launch opportunities to educational institutions, non-profit organizations and NASA Centers. Since its inception the CubeSat Launch Initiative has launched 46 CubeSats flown on 12 ELaNa Missions from 28 unique organizations and has selected 119 CubeSat missions from 66 unique organizations. Educational Launch of Nanosatellites (ELaNa) missions have included: BisonSat the first CubeSat built by a tribal college, TJ3Sat the first CubeSat built by a high school and STMSat-1 the first CubeSat built by an elementary school. NASA releases an Announcement of Opportunity[96] in August of each year with selections made the following February.

Artemis 1

NASA initiated the Cube Quest Challenge in 2015, a competition to foster innovation in the use of CubeSats beyond low Earth orbit. The Cube Quest Challenge offers a total of $5 million to teams that meet the challenge objectives of designing, building and delivering flight-qualified, small satellites capable of advanced operations near and beyond the Moon. Teams compete for a variety of prizes in lunar orbit or deep space. 13 CubeSats from different teams are planned be launched to cislunar space between 2020 and 2021 as secondary payloads on board the Artemis 1.

ESA "Fly Your Satellite!"

"Fly Your Satellite!" is the recurring CubeSatsprogramme of the Education Office of the European Space Agency. University students have the opportunity to develop and implement their CubeSat mission with support of ESA specialists. Participating student teams can experience the full cycle from designing, building, and testing to eventually, the possibility of launching and operating their CubeSat. The fourth iteration of the Fly You Satellite! programme closed a call for proposals in February 2022.

Canadian Cubesat Project

The Canadian Space Agency announced the Canadian CubeSat Project (CCP) in 2017, and the participating teams were selected in May of 2018. The programme provides funding and support to one university or college in each province and territory to develop a CubeSat for launch from the ISS. The objective of the CCP is to provide students with direct hands on experience in the space industry, while preparing them to enter into a career in the space domain.

QB50

QB50 is a proposed international network of 50 CubeSats for multi-point, in-situ measurements in the lower thermosphere (90–350 km) and re-entry research. QB50 is an initiative of the Von Karman Institute and is funded by the European Commission as part of the 7th Framework Programme (FP7). Double-unit (2U) CubeSats (10×10×20 cm) are developed, with one unit (the 'functional' unit) providing the usual satellite functions and the other unit (the 'science' unit) accommodating a set of standardised sensors for lower thermosphere and re-entry research. 35 CubeSats are envisaged to be provided by universities from 22 countries around the world, among them 4 are from the US, 4 from China, 4 from France, 3 from Australia and 3 from South Korea. Ten 2U or 3U CubeSats are foreseen to serve for in-orbit technology demonstration of newspace technologies.

The Request for Proposals (RFP) for the QB50 CubeSat was released on February 15, 2012. Two "precursor" QB50 satellites were launched aboard a Dnepr rocket on June 19, 2014. All 50 CubeSats were supposed to be launched together on a single Cyclone-4 launch vehicle in February 2016, but due to the unavailability of the launch vehicle, 36 satellites were launched aboard Cygnus CRS OA-7 on 18 April 2017 and subsequently deployed from the ISS. A dozen other CubeSats have been manifested on the PSLV-XL C38 mission in May 2017.

Launch And Deployment

Figure1.16 A Dnepr rocket launching from ISC Kosmotras

Unlike full-sized spacecraft, CubeSats have the ability to be delivered into space as cargo and then deployed by the International Space Station. This presents an alternative method of achieving orbit apart from launch and deployment by a launch vehicle. NanoRacks and Made in Space are developing means of constructing CubeSats on the International Space Station.[109]

Current Launch Systems

NASA's CubeSat Launch Initiative launched more than 46 CubeSats on its ELaNa missions over the several years prior to 2016, and as of that time, 57 were manifested for flight over the next several years. No matter how inexpensive or versatile CubeSats may be, they must hitch rides as secondary payloads on large rockets launching much larger spacecraft, at prices starting around $100,000 as of 2015. Since CubeSats are deployed by P-PODs and similar deployment systems, they can be integrated and launched into virtually any launch vehicle. However, some launch service providers refuse to launch CubeSats, whether on all launches or only on specific launches, two examples as of 2015 were ILS and Sea Launch.

SpaceX and Japan Manned Space Systems Corporation (JAMSS) are two recent companies that offer commercial launch services for CubeSats as secondary payload, but a launch backlog still exists. Additionally, India's ISRO has been commercially launching foreign CubeSats since 2009 as secondary payloads. On 15 Feb 2017, ISRO set the world record by launching 103 CubeSats on board its Polar Satellite Launch Vehicle for various foreign companies ISC Kosmotras and Eurockot also offer launch services for CubeSats. SpaceX beat this record in 2021 with the Transporter-1 (spaceflight) carrying 143 spacecraft to orbit. Rocket Lab specializes in launching CubeSats on its Electron from New Zealand.

Future and Proposed Launch Systems

On 5 May 2015, NASA announced a program based at the Kennedy Space Center dedicated to develop a new class of rockets designed specifically to launch very small satellites: the NASA Venture Class Launch Services (VCLS), which will offer a payload mass of 30 kg to 60 kg for each launcher. Five months later, in October 2015, NASA awarded a total of $17.1 million to three separate startup launch companies for one flight each: $6.9 million to Rocket Lab (Electron rocket); $5.5 million to Firefly Space Systems (Alpha rocket); and $4.7 million to Virgin Galactic (LauncherOne rocket). The payloads for the three flights under the VCLS contract have not yet been assigned. Other small satellite launch systems are under development that would carry CubeSats alongside a small payload, including the Neptune series of rockets by Interorbital Systems, Garvey Spacecraft's Nanosat Launch Vehicle, and the SPARK rocket. In addition to conventional launch vehicles and launch facilitators like KSF Space, several air launch to orbit vehicles are in the works by Swiss Space Systems, Generation Orbit Launch Services, and Boeing (in the form of their Small Launch Vehicle).
Many of the aforementioned characteristics or properties of CubeSats such as structure, propulsion, material, computing and telecommunications, power, and any additional specific instruments or measurement devices pose challenges to the expansion of use of CubeSattechnology beyond Earth's orbit. These challenges have been increasingly under consideration of international organizations over the past decade, for example, proposed in 2012 by NASA and the Jet Propulsion Lab, the INSPIRE spacecraft is an initial attempt at a spacecraft designed to prove the operational abilities of deep space CubeSats. The launch date was expected to be 2014, but has yet to do so and the date is currently listed by NASA as TBD.

Deployment

P-PODs (Poly-PicoSatellite Orbital Deployers) were designed with CubeSats to provide a common platform for secondary payloads. P-PODs are mounted to a launch vehicle and carry CubeSats into orbit and deploy them once the proper signal is received from the launch vehicle. The P-POD Mk III has capacity for three 1U CubeSats, or other 0.5U, 1U, 1.5U, 2U, or 3U CubeSats combination up to a maximum volume of 3U. Other CubeSatdeployers exist, with the NanoRacksCubeSatDeployer (NRCSD) on the International Space Station being the most popular method of CubeSat deployment as of 2014. Some CubeSatdeployers are created by companies, such as the ISIPOD (Innovative Solutions In Space BV) or SPL (Astro und FeinwerktechnikAdlershof GmbH), while some have been created by governments or other non-profit institutions such as the X-POD (University of Toronto), T-POD (University of Tokyo), or the J-SSOD (JAXA) on the International Space Station. While the P-POD is limited to launching a 3U CubeSat at most, the NRCSD can launch a 6U (10 cm × 10 cm × 68.1 cm (3.9 in × 3.9 in × 26.8 in)) CubeSat and the ISIPOD can launch a different form of 6U CubeSat (10 cm × 22.63 cm × 34.05 cm (3.94 in × 8.91 in × 13.41 in)).

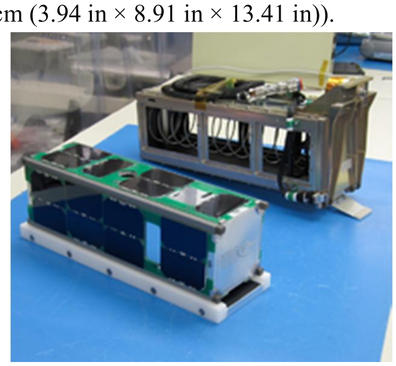


Figure1.17 CSSWE next to its P-POD before integration and launch

While nearly all CubeSats are deployed from a launch vehicle or the International Space Station, the NanoSail-D2, a 3U CubeSat. This was done again with the Cygnus Mass Simulator as the primary payload launched on the maiden flight of the Antares rocket, carrying and later deploying four CubeSats. For CubeSat applications beyond Earth's orbit, the method of deploying the satellites from the primary payload will also be adopted. Eleven CubeSats are planned to be launched on the Artemis 1, which would place them in the vicinity of the Moon. InSight, a Mars lander, also brought CubeSats beyond Earth orbit to use them as relay communications satellites. Known as MarCO A and B, they are the first CubeSats sent beyond the Earth–Moon system. Chasqui I saw a unique deployment process, when it was deployed by hand during a spacewalk on the International Space Station in 2014.

II. Literature Survey

2.1 Preliminary Design Of Nano Satellite For Regional Navigation System

L Fathurrohim, R E Poetro, B kurniadi, P A Fadillah and M Iqbal(2019 sep 23)

This journal give us the use of Nano satellites and its accomplishment in Naviogation. A Low cost Regional Navigation Satellite System employing constellation of nano satellites has been proposed for Indonesian coverage. The constellation of Low Earth Orbit nano satellites off course will not be able to give better position fixed to the GPS. However, the design of navigation system has much lower in cost compare to the current navigation system. This paper tells about preliminary design of the proposed regional navigation satellite system. The results of our satellite design has 3 kg on its weight, 10 W on power requirement at the peak condition, and 2.7 years of lifetime. Payload communication of the satellite will use UHF and TT&C communication will use VHF. Total area of solar panel will be 0.11 m2 .

2.2 Ground to Space Quantum Key And Entanglement Distribution Using A Nanostalite

T Jennewein,CGrant,EChoi,CPung.C Holloway(2018)

From this journal we got the idea of how Nano satellite are used in current mission and their working in remote sensing. The NanoQEY (Nano Quantum Encryption) Satellite is a proposed nanosatellite mission concept developed by the Institute for Quantum Computing (IQC) at the University of Waterloo and the Space Flight Laboratory (SFL) at the University of Toronto Institute for Aerospace Studies (UTIAS) that would demonstrate long-distance quantum key distribution (QKD) between two distant ground stations on Earth using an optical uplink. SFL's existing and proven NEMO (Nanosatellite for Earth Monitoring and Observation) bus forms the baseline spacecraft for NanoQEY, with a QKD receiver payload designed by IQC. The primary objective of the NanoQEY mission would be to successfully distribute at least 10 kbit of secure key between two optical ground stations, where the satellite acts as a trusted node. The secondary mission objective would be to perform Bell tests for entangled photons between ground and space. We designed a compact QKD receiver payload that would be compatible with the mass, volume, power and performance constraints of a low-cost nanosatellite platform. The low-cost rapid schedule "microspace" approach of UTIAS/SFL would allow for the proposed NanoQEY mission to be developed in 2.5 years from project kick-off to launch of the spacecraft, followed by a one-year on-orbit mission.

2.3 Design And Analysis Of Trajectory Calculation From Nano Satellite In Leo

Raja Munusamy, ManishaKumari, Jasmine Kaur,UtsaNangalia(sepetember 2019)

Nano satellites or Cube satellites technology is gradually emerging as an important technology in space industry and the designing of these satellites are discussed in this journal. Nano satellite or cube satellite technology is gradually emerging as an important technology in space industry over the last two decades. The space emerging countries and nonspace countries are now in a race to operate small satellite mission. It is becoming popular among developing countries because of cost effective programme with great capability. The small satellite in space activity is extending the number of satellites for specific designed mission both for civilian and defence purpose. So, the number of associated launches, ground station and data collection and distribution system are getting more importance than ever. That is why the demand of LEO satellite tracking system for data collection and distribution is increasing. The three Nano satellite chosen, each serve different research purpose is launch by Indian Space Research Organization (ISRO). Jugnu is built under the supervision of Dr. N. S. Vyas, which is capable to provide information on agriculture and disaster monitoring. INS-1A and INS-1B, which stands for ISRO nanosatellite, are part of the constellation of 104 satellites is developed by ISRO. The coordinates and satellite orbit trajectory were determined, and the orbit has been analyzed using three software‟s namely GMAT, STK and Orbitron and the differences in the orbit scenario. The project is analyses the orbits of three satellites in total and compare with the respective software‟s along with a MATLAB software interfacing of the data acquired.

2.4 Cubesats And Small Satellites

Jermy Straub, Michael Swartwout, Miguel Nunes and VaiosLappas

This journal gives us the overview of cubesats and the technology involved in them , and the Progress involed in sending them to Low Earth Orbit.CubeSats and other small satellites have advanced from being perceived as toys and only suitable for educational purposes to robust platforms for conducting space missions. They have been used for commercial and government and military purposes, in addition to bona fide science and educational purposes . Constellations of small satellites are currently being deployed for imaging and other data collection purposes. Small satellites have also served as testbeds for numerous innovative concepts, mitigating risk and preparing them for prospective use in other space missions. With the incredible growth in a small spacecraft—and the proximal launch of the 1,000th CubeSat, there are still numerous logistical and technical considerations that need to be explored. The discipline is still quite young as well: questions of nomenclature, licensing, deorbiting, and producing orbital debris abound. Some look at small satellites as harbingers of a new space age; others—perhaps—are more concerned with the potential that they may harm a more expensive spacecraft.

2.5 Satellite Forensics " Analysing Sparse Beacon Data To Reveal The Fate Of Dtu Sat – 2 "

-W Fleron(5 May 2019)

From this journal they used the nano satellites to analysis the DTU Sat-2 and corrected its error which resulted in extended life time of the satellite. Our investigation has led us to the conclusion that the onboard battery has been destroyed as a consequence of two errors in the satellite. Wrong value of four resistors in the power system battery protective circuitry results in too low limit values of the battery charging cycle. The passive attitude system optimized for antenna directivity results in low power generation during passage over northern Africa. In combination, this results in deep discharge of the battery with no possibility of recovery, and ultimately, the battery has suffered permanent damage. Once the battery has been discharged, the 3.3 V power bus voltage is not stabilized. This means that when resetting occurs either due to eclipse or magnetically induced attitude changes, the OBC booting sequence may fail due to voltage fluctuations of the 3.3 V power bus. A failed OBC boot leads to extra power expenditure as the OBC beacon vacancies are filled with the longer COM beacon making it even harder for the battery to recover.

2.6 Attitude Analysis Of Small Satellites Using Model-Based Simulation

Samir A. Rawashdeh

SNAP extends from simulations developed between 2009 and 2012 as graduate research at the University of Kentucky advised by Dr. James E. Lumpp, Jr. Funding for this work and publication were covered by internal resources at the University of Michigan-Dearborn.

2.7 Modular Design Of Rf Front End For A Nanosatellite Communication Subsystem Tile Using Low-Cost Commercial Components

HaiderAli , Anwar Ali , M. Rizwan Mughal ,Leonardo Reyneri,ClaudioSansoe and JaanPraks

The paper presents a modular approach for a RF front-end design by using COTS components that are low priced and readily available for development. This makes the design more feasible for small industries and academia to develop their own satellite subsystems. Moreover, there is a degree of modularity at the design, schematic, and physical levels which can significantly reduce the subsystem manufacturing and design cost and development time. The abovementioned work is the authors' intellectual property and research work. All the data needed to support the research work is available. An earlier version of this study was presented as an abstract at the 65th International Astronautical Congress 2014. The authors declare that they have no conflicts of interest.

2.8 High-Resolution Image And Video Cubesat (Hirev): Development Of Space Technology Test Platform Using A Low-Cost Cubesat Platform

Dong-Hyun Cho, Won-Sub Choi,Min-Ki Kim, Jin-HyungKim,EunsupSim

In this paper, we present high-resolution image and video CubeSat (HiREV), the first constructed 6 U platform to reach the space technology test bed stage, developed by the Korea Aerospace Research Institute (KARI). The CubeSat system is a low-cost platform that has been widely applied to various space missions, from missions involving earth observation to deep space. Despite the emergence of the CubeSat technology worldwide, the CubeSat market in Korea is still in the beginning stages, and a standard testing platform is also in demand. For this reason, KARI is starting to develop a 6 U CubeSat platform, which includes a less than 3 U bus system and greater than 3 U payload space. HiREV has been developed with locally manufactured parts, creating a domestic commercial off-the-shelf infrastructure for CubeSat and 3 m resolution camera payload development. Core flight software has also been applied as an on-board flight software system. Presently, we have developed the main system, while HiREV is under space environmental testing.

2.9 Cubesat Communications: Recent Advances and Future Challenges

Nasir Saeed; **Ahmed Elzanaty**; **HebaAlmorad**; **HayssamDahrouj**; **Tareq Y. Al-Naffouri**

Given the increasing number of space-related applications, research in the emerging space industry is becoming more and more attractive. One compelling area of current space research is the design of miniaturized satellites, known as CubeSats, which are enticing because of their numerous applications and low design-and-deployment cost. The new paradigm of connected space through CubeSats makes possible a wide range of applications, such as Earth remote sensing, space exploration, and rural connectivity. CubeSats further provide a complementary connectivity solution to the pervasive Internet of Things (IoT) networks, leading to a globally connected cyber-physical system. This paper presents a holistic overview of various aspects of CubeSat missions and provides a thorough review of the topic from both academic and industrial perspectives. We further present recent advances in the area of CubeSat communications, with an emphasis on constellation-and-coverage issues, channel modeling, modulation and coding, and networking. Finally, we identify several future research directions for CubeSat communications, including Internet of space things, low-power long-range networks, and machine learning for CubeSat resource allocation.

2.10 General Analysis Of Cube Satellite Technology: An Overview

Ritwik Sinha,AnanyaVerma

CubeSat technology has become a tool to encourage engineering collaboration, to train students providing them with a platform for real-world space exploration. This provides advancements in the aerospace industry as well. These satellites are made for a rather specific purpose than a conventional heavyweight satellite thereby reducing the cost. This paper discusses Cube Satellites, their design, salient features along with different applications and advancements made in the field of CubeSat technology thus providing an overview of a general analysis of CubeSat technology.CubeSats are a great source of learning which helps in research related activities as well. The exploration level with the use of these devices acts as a major activity. A conventional satellite weighing far more than that can for sure carry many instruments but CubeSat is a cheap and attractive option for a rather specific goal.

2.11 Horus: Multispectral and Multiangle Cubesat Mission Targeting Sub-Kilometer Remote Sensing Applications

Alice Pellegrino,Maria Giulia Pancalli,AndreaGianfermo,PaoloMarzioli

This paper presents the HORUS mission, aimed at multispectral and multiangle (nadir and off-nadir) planetary optical observation, using Commercial Off-The-Shelf (COTS) instruments on-board a 6-Unit CubeSat. The collected data are characterized by a sub-kilometer resolution, useful for different applications for environmental monitoring, atmospheric characterization, and ocean studies. Latest advancements in electro-optical instrumentation permit to consider an optimized instrument able to fit in a small volume, in principle without significant reduction in the achievable performances with respect to typical large-spacecraft implementations. CubeSat-based platforms ensure high flexibility, with fast and simple components' integration, and may be used as stand-alone system or in synergy with larger missions, for example to improve revisit time. The mission rationale, its main objectives and scientific background, including the combination of off-nadir potential continuous multiangle coverage in a full perspective and related observation bands are provided. The observation system conceptual design and its installation on-board a 6U CubeSat bus, together with the spacecraft subsystems are discussed, assessing the feasibility of the mission and its suitability as a building block for a multiplatform distributed system

III. Project Plan

3.1 Project Idea:

- Cubesat are designed and manufactured in small sizes so that it can be cost effective and compact size to be launched together with a standard satellite.
- These satellite with future technological improvements can even replace the standard satellite in performance and cost.
- Our goal is to show the effectiveness of Cubesat in space research.
- A typical cubesat are built to standard dimensions of 10cm x 10cm(units or “U”) and weigh less than 1.33 kg per U.
- Basically we are trying to pair up a series of cubesat’s in an orderly formation with it’s center focused mainly receiving and transferring command from base to the surrounding Cubesat’s

3.2 Eleborate View:

- A standard cubesat typically cost around $40 million whereas a cube sat only cost about $50,000 - $1 million.
- So even with multiple cubesat the cost will be relatively low . In our project we are trying to form a grid formation of grid shape in low earth orbit of 3x3 with 9 grid points.
- We are planning a coordinated system of satellite with the center grid point as the main transceiver with transmit command from base to the surrounding cubesat.
- We came up with this idea because for a cubesat implanted with a transceiver which can contact the ground station there is a complex system required.
- So we made the main cubestats progressing the main mission fitted with a limited range transceivers and made them so that they transfer information to the central cubesat with main function of relaying information to the ground station .
- With this, the cubesat’s can perform in a coordinated manner and provide information with increased accuracy.
- Our project can prove useful in attaining information with greater accuracy than a standard satellite
- Since every satellites are in constant connection with the central cubesat ,it proves useful to operate multiple cubesat with a single command from the ground station.
- The ground station can sort the acquired information from these satellites and process those information even in the central cubesat.
- The central cubesat only consist of high range transceiver, multiple processor for sorting out the information's obtained and solar panels for power supply.
- The other cubesat’s consists of thermo graphical sensor for ground surface analysis and even imaginary processing sensors such as camera.
- If formed in this formation we can make cubesats with specified role to play in the mission, that is that the cubesat can be fitted with specific sensor with superior versions
- We have planed to make a cube sat with grid formation.
- This grid formation will contain a main satellite and each satellite are connected with it.
- We have planed to make a 4 grid formation with a main satellite in center.
- Each cube sat are specified with its own components.
- All satellite are interlinked with each other.
- The main satellite was carried out with transmitter and receiver with ultra high frequency.
- The cube sat are formed with high frequency which will make the sat to consume less power.

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3.3 Content of Grid Forming Satellite:

- The grid formation have 4 satellite are
  - 1U cube sat which have temperature sensor.
  - 1U cube sat contain pressure sensor.
  - 1U cube sat with accelerometer.
  - 1U cube sat with camera and remote sensing sensor.
- The main satellite contain transmitter and receiver with additional processor which collect the entire data from each cube sat and deliver .
- The grid formation will carried out by rocket with the positioning formation.
- If any satellite will got damaged it will be easily known by the main satellite due to there inter connections.
- So it is highly efficient and it will cost low budget due to multiple cube sat with grid formation.

3.4 Dimension of Cube Sat

CubeSat Designation	Size (max)	Mass (max)
Cube (1U)	10 cm x 10 cm x 10 cm	1 kg

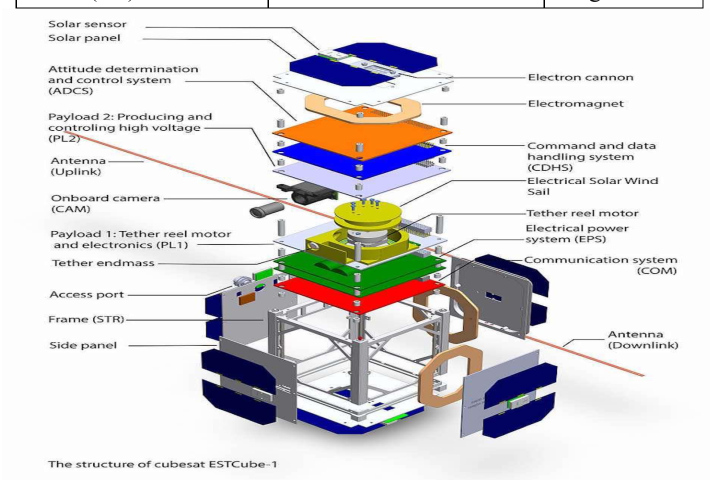

Figure 3.1 Cube Sat

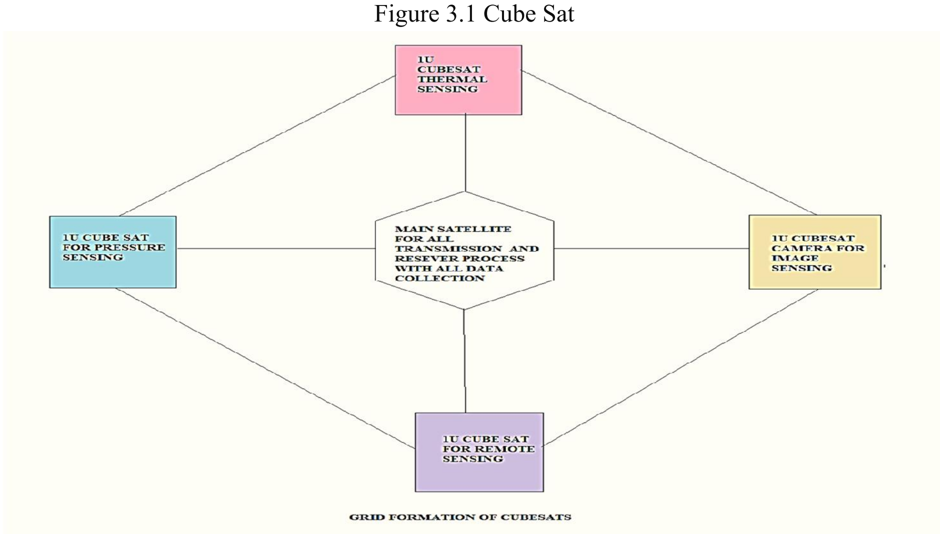

Figure 3.2 Grid formation of Cubesat

- The above diagram is the model view of our project grid formation

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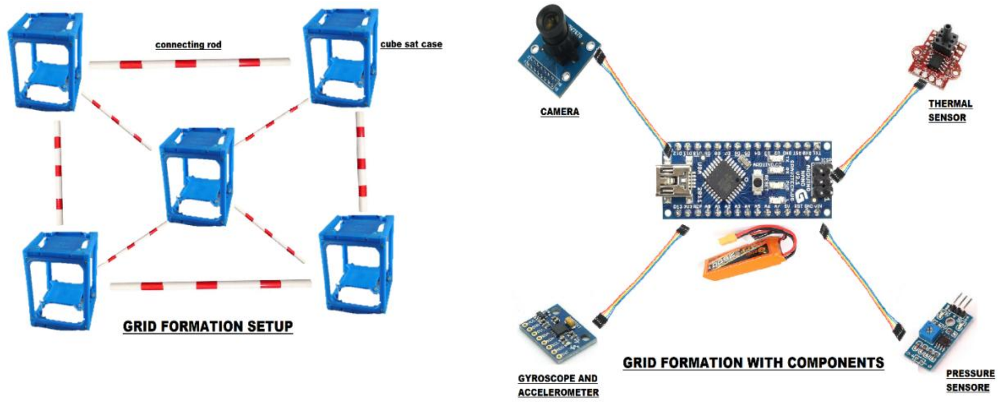

Figure 3.3 Cube sat components

IV. Components Required

4.1 Arduino Mega 2560

The **Arduino Mega 2560** is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega 2560 board is compatible with most shields designed for the Uno and the former boards Duemilanove or Diecimila.

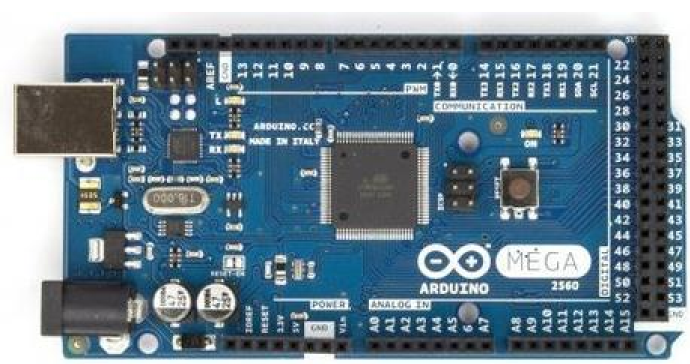

Figure 4.1 Arduino mega 2560

4.2 Arduino Cable

The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3. x). It has more or less the same functionality of the ArduinoDuemilanove, but in a different package. It lacks only a DC power jack, and works with a **Mini-B USB cable** instead of a standard one.

Figure 4.2 Arduino Cable

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4.3 Jumper Wires

A jump wire (also known as jumper, jumper wire, DuPont wire) is an electrical wire, or group of them in a cable, with a connector or pin at each end (or sometimes without them – simply "tinned"), which is normally used to interconnect the components of a breadboard or other prototype or test circuit, internally or with other equipment or components, without soldering. Individual jump wires are fitted by inserting their "end connectors" into the slots provided in a breadboard, the header connector of a circuit board, or a piece of test equipment.

Figure 4.3 Jumper Wire

4.4 BMP280 Pressure Sensor

The BMP280 is an absolute barometric pressure sensor, which is especially feasible for mobile applications. Its small dimensions and its low power consumption allow for the implementation in battery-powered devices such as mobile phones, GPS modules or watches. The BMP280 is based on Bosch's proven piezo-resistive pressure sensor technology featuring high accuracy and linearity as well as long-term stability and high EMC robustness. Numerous device operation options guarantee for highest flexibility. The device is optimized in terms of power consumption, resolution and filter performance. The BMP280 can only measure temperature and air pressure, while the BME280 can measure humidity in addition to temperature and air pressure.

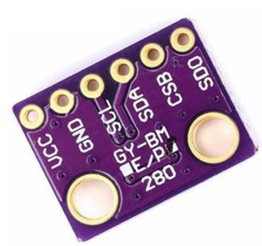

Figure 4.4: Pressure Sensor

4.5 Dht11 Digital Humidity Sensor

The **DHT11** is a commonly used **Temperature and humidity sensorthat** comes with a dedicated NTC to measure temperature and an 8-bit microcontroller to output the values of temperature and humidity as serial data.

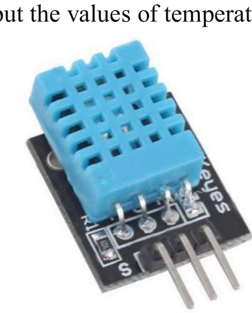

Figure 4.5 Humidity Sensor

4.6 MPU6050 Gyroscope Sensor

MPU6050 sensor module is complete 6-axis Motion Tracking Device. It combines 3-axis Gyroscope, 3-axis Accelerometer and Digital Motion Processor all in small package. Also, it has additional feature of on-chip Temperature sensor. It has I2C bus interface to communicate with the microcontrollers.

It has Auxiliary I2C bus to communicate with other sensor devices like 3-axis Magnetometer, Pressure sensor etc.

If 3-axis Magnetometer is connected to auxiliary I2C bus, then MPU6050 can provide complete 9-axis Motion Fusion output.

Figure 4.6 Gyroscope Sensor

4.7 Ov7670 Camera Sensor

Ov7670 640x480 VgaCmos Camera Image Sensor Module Is A Low-Cost Image Sensor, Dsp That Can Operate At A Maximum Of 30 Fps And 640 X 480 (“Vga”) Resolutions, Equivalent To 0.3 Megapixels.

The Captured Image Can Be Pre-Processed By The Dsp Before Sending It Out. This Pre-Processing Can Be Configured Via The Serial Camera Control Bus (Sccb). Omnivision Ov7670 CmosVga (640×480) Camera-Chip Sensor WithOmnipixel Technology 3.3v Dc Input Voltage. Working Temp. 0-50 Degree Celsius All Glass Lenses, Lens(Including Seat) Is Magnesium Alloy Material.

Focal Length Of Lens Is 3.6 Mm 650 Nm Bands Black Fr-4 Pcb, Quality Heavy Gold Plate, Effectively Prevent The Pcb From Light Leak Issues And Prevents Shadow In Images 2×10 0.1″ Output Connector For Convenient Insertion Into Prototype Board, Bread Board, Mcu Onboard Connectors This Camera Module Is Very Powerful And Easy-To-Interface With 8/16/32 Bit Micro-Controller. Ov7670 640x480 VgaCmos Camera Image Sensor Module Will Provide Vision To Your Small Embedded Systems And Will Be Useful For Plenty Of Applications In Robotics.

Image Processing, Simple Machine Vision, Object Detection, Color Detection, Etc. 2×10 0.1″ Output Connector Will Be Easy To Plug Into Any Prototype Board Or Breadboard Which Will Make Your Project/Product Implementation Fast. Technical Parameters: High Sensitivity For Low-Light Operation Low Operating Voltage For Embedded Portable Apps Lens Shading Correction Flicker (50/60 Hz) Auto-Detection Saturation Level Auto Adjust (Uv Adjust) Edge Enhancement Level Auto-Adjust.

Figure 4.7 camera

4.8 Ultrasonic Sensor HC-SR04

This is the HC-SR04 ultrasonic distance sensor. This economical sensor provides 2cm to 400cm of non-contact measurement functionality with a ranging accuracy that can reach up to 3mm. Each HC-SR04 module includes an ultrasonic transmitter, a receiver and a control circuit.

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There are only four pins that you need to worry about on the HC-SR04: VCC (Power), Trig (Trigger), Echo (Receive), and GND (Ground). You will find this sensor very easy to set up and use for your next range-finding project!
This sensor has additional control circuitry that can prevent inconsistent "bouncy" data depending on the application.

Figure 4.8 Ultra Sonic Sensor

V. CONCLUSION

This paper gives us the detailed advantage of the cubesat and its resourceful use in space missions. Further the method of using the cubesat in a grid formation explains that there are more than one way of using this satellites and the future development in technology can bring a diverse variety in the use of cube sat. As mentioned of the cubesat in grid formation with the main communicating cubesat in the centre of the formation and surrounded with the cubesat's equipped with advanced superior sensors that can give us a detailed and accurate information of the targeted area. By using the grid formation method one can use the cubesat's to observe multiple targets and can simultaneously analyze the information obtained. The cubesat for remote sensing give the information about the target's geography, temperature, humidity, altitude, etc. By analyzing the information's obtained the land can be observed and the environment in this land can be calculated without the need for direct observation by the officers.