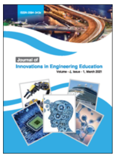

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THAPATHALI CAMPUS
Institute of Engineering
Tribhuvan University

PocketQube development for earth exploration and vegetation monitoring

Rabin Dhakal [a,*], Abhishek Ghimire [a], Sanjay Nepal [a] and Kapalik Khanal[a]

[a]*Department of Electronics and Computer Engineering, Thapathali Campus, Institute of Engineering, Tribhuvan University, Kathmandu, Nepal,*

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Abstract

A PocketQube is being popular these days due to the enhancement in technologies for space research and earth observation. It is extremely vital to analyze the condition of vegetation on the earth surface because deforestation, forest fire and smuggling of precious plants have been increasing dramatically. The camera module in the payload captures the image from the space which helps in analyzing the vegetative condition of the forest on the earth's surface. The provided image data is huge in order to maintain the quality of the images it captures. Hence, the received image data is further divided into chunks. Each chunks holds 64bits of hex values of each pixels of the image. The subsequent real time Image data is transmitted to the ground station and the received image is checked, analyzed and displayed on the screen. The received data is regenerated by combining the received chunks at a time at ground station. Based on the provided images further image processing activities are conducted in order to understand the condition of vegetation by calculating the vegetative index of each pixels in the received images.

1. Introduction

The CubeSat development time started with effort in 1999 between Jordi Puig-Sauri, a professor at California Polytechnic State University(Cal Poly), and Bob Twiggs, a professor at Stanford University's Space Systems Development Laboratory (SSDL). The collaborated effort was to provide the access to the space exploration for the Science students community in the Universitites. This project was succesfully completed. Many University launched the space program after successful development of the CubeSat [1] . Small dimension CubeSat has technically helped with reduced cost in the field of Technical development and Scientific Investigation.

In the context of Nepal, Nepal has recently launched the first Cubesat named as NepaliSat-1 in space with joint effort of Nepalese scientist Aabhas Maskey and Hariram Shrestha at BIRDS project of Japanese Kyushu Institute of Technology with joint effort of Nepal Academy of Science and Technology. The CubeSat was launched from Virginia Space's Mid-Alantic Regional Spaceport at NASA's Wallops Flight Facility in United States. NepaliSat-1 taken by cargo spaceship lifted into space by the rocket. It weigh approximately 1.3kg. The orbit lies about 400km from the earth surface. During each revolution, CubeSat captures the image of the surface for six to ten minutes during each revolution. Nepalisat-1 assumed to revolve around the earth for at least six months [2] . It is been a fact that earth is getting hot every year. The temperature around the world has been rising dramatically since Industrial Revolution. According to the research conducted by the Scientists at NASA's Gorrard Institute for Space Studies(GISS), the average temperature all around the globe has increased by 1 degree Celsius since 1880 [3] . The culture of earth observation through sending images of the started on October 24, 1946 where US launched V-2 flight which took pictures in every 1.5 seconds. It stayed on the sub-orbital position in the space and it was 65 miles far from the surface which was considered much more higher than previous record of 13.7 miles. Explorer II ballon mission was launched in 1935 which captured the image from 13.7miles height. As the times passed continously,

*Corresponding author:
tha073bex330@tcioe.edu.np (R.D.)

US Explorer 6 the first image was taken from the orbital path on August 14, 1959. Soviet Union also launched LUNA 3 satellite which took the image of the far side of Moon on October 6, 1959. In 1972, US inaugurated Landsat program which was the largest program for acquiring the images of different geolocation of earth surface from the space. Real time satellite image data acquisition was started by United KH-11 satellite. On February 11, 2013 Landsat Data Continuity Mission was launched which helped in acquiring the high quality images of different geographic locations on earth [4] . Nepal, having launched its first satellite, is quite behind the rest of the world in the field of satellites and aerospace engineering. Despite successfully deploying from International Space Station, satellite named NepaliSat-1, which has already orbiting the Earth [5] . Moreover the satellite is being used to send pictures as well as to test the range of a Lo-Ra devices.

2. Related Works

Space Engineers are focusing on gathering the high performance from the small satellites in governing and observing the condition of the earth surface. Newly faciliated innovation called commercial off-the-self (COTS) are getting important for the last few decades. Recently developed satellites from the universities for the reasearch purpose has been realising cost-effective techniques packed with decent capacity of earth observation [6] .

The small satellite mission launched in 2017 from the International Space Station into the low earth orbit. The tiny satellite was named as ASTERIA (Arcsecond Space Telescope Enabling Research in Astrophysics) spacecraft. It helped in detecting the exoplanet known as 55 Cancri e [7] . The satellite provided the information that the planet was burning hot and twice the size of Earth. The satellite was originally designed to perform the technological demostration and research tasks. ASTERIA, a 6U cubesat which was deployed to conduct the high-precision pointing control and high-stability thermal control. It helped in gathering the photometric data of the exoplanet, This was the first detection of the exoplanet by any CubeSat [8] .

With the joint collaboration between universities and NASA's Johnson Space Center, ElaNa 41 mission is initiated. CubeSats are playing vital role in scientific research, educational investigations, and technological demonstations at NASA [9] . QubeSat is another technologoy demonstation mission that tests the space conditions on quantam gyroscopes using nitrogen-vacancy centers in diamond [10] .

3. Methodology

This section explains the methodologies used in the system's design and implementation.

3.1. PocketQube Subsystem Architechture

The CubeSat subsystem is mainly based on the bus architecture, where there is master-slave subsystem. The C&DH (command and data handling) acts as a master and other subsystems acts as a slave. These Subsystem take care about the necessary considerations required for the CubeSat to operate in high altitude. ADCS (Altitude Determination and Control System) help in balancing the satellite in the high altitude. Another most useful subsystem for the satellite to operate is power generation and management system called EPS (Electrical Power System). The COMM (Communication Subsystem) al-

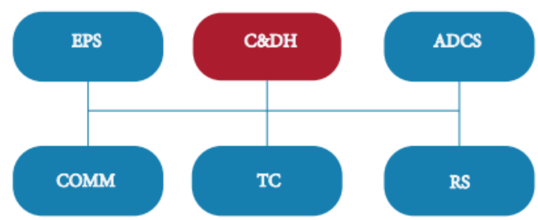

Figure 1: subsystem architecture

lows to establish connection between the CubeSat and the Ground Station. It mainly uses Communication board for the communication in small satellites. TC (Thermal Control) Subsystem is also useful to balance the temperature of the satellite due to direct exposure in the sunlight. RS (Remote Sensing) subsystem extends from image capturing process, image transmission and image processing. Image is further analyzed to calculate the NDVI (Normalized Difference Vegetation Index) which governs the percentage of vegetation in the specific geographical area. Finally, C&DH subsystem controls these subsystems together for the specific application of the device. C&DH subsystem provides the necessary signals to the slaves which performs the specific tasks. RS system serves as data acquisition instruments for experiments in different fields, either in study or research in earth surface as well as deep space in Universe. The RS systems are not limited to capturing images in visible spectrum, but they also allow to capture representations in other bands of electromagnetic spectrum as near infrared (NIR) or Infrared (IR). The Filters used in the camera module prohibits the other band of frequency rather than visible spectrum to enter in the image sensor

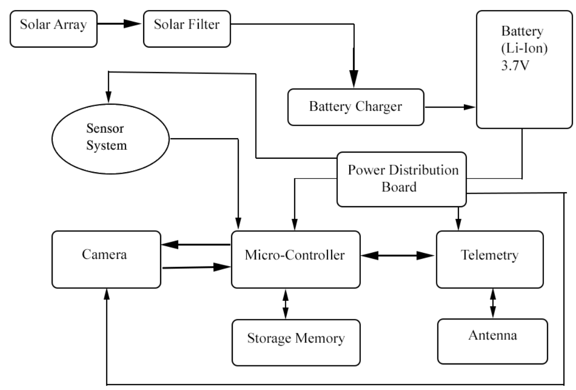

Figure 2: System block diagram

3.2. System block diagram

PocketQube is a cube-satellite which is implied for transmitting images from 45ft height to the ground station located to the earth. Two megapixels' camera, OV2640 is deployed onto the system which captures the images of Geographical region. The earth observing cube produces the JPEG image in compressed size. SRAM is integrated for storage memory in the system. The captured images are stored in the storage device allocated inside the proposed system.The sensoring system includes the Accelerometer, Gyrometer, Magnetometer and Pressure sensor. The data of the sensor is sent to the ground station. Radiation sensors are also used for radiation measurement. The transmitted image are analyzed and studied at the ground station. The communication with satellite and ground station is carried out using RF transmitter and receiver. Satellite receives the signal from antenna and starts its processing according to the frequency of signal provided to it.

The supply from the solar arrays which is embedded on the four sides of the system is passed through the balance battery charger which always passes the required amount of voltage to the chargeable battery for maintaining the efficiency and performance of the system. It controls the overloading and deficiency of power. Power for the components of the PocketQube is supplied through the battery.

The camera captures the image and radiation sensor reads the radiation value. Also, other implemented sensors reads the corresponding values of pressure, position, angular velocity and magnetic field. The captured image is saved to SRAM. For the transmission of captured image, microcontroller reads the image from memory and then divides it into chunks. Each chunks are transmitted to ground station via communication module. After successfully receiving the image, Python and QGIS software are used to analyze the NVDI.

After successful transmission of the Image in the ground station, the vegetation percentage in the transferred image is calculated with the help of NDVI. The received hex value of the image is assembled together in order to generate image captured by the camera. Then the image is further analyzed to get the NDVI in the image.

4. Implementation Details

The details involved collaborating different sections together in order to implement and are described in the section below.

4.1. Communication System Modelling

The communication system deals with the connection between the payload located at the distant apart and ground station, ready to receive data of the images. Payload mission data provides the necessary details of the observed quantity through the communication channel. The payload / Telemetry is 1200bps and uplink telemetry can have data rate up to 300bps. VHF/UHF range transceiver is used as a telemetry for satisfying the modulation with necessary frequency. Dipole antenna is used in the CubeSat for transmission of captured images. VHF/UHF transceiver helps in communication in far range application with high speed pf transmission. The GFSK modulation is used for transmitting from the CubeSat to the Ground Station. An antenna is the key element for transmitting and receiving the data. A satellite without Antenna system is considered as a dead satellite. Considering the power as Pt, The flux density S is W/m2 of an isotopically radiating antenna at a given distance d can be calculated using the following formula in Equation 1:

$$S = \frac{Pt}{4\pi d^2} \tag{1}$$

Although this is an ideal antenna because a real isotropic antenna is not possible and any physical antenna have directivity which directs in certain direction [11]. Hence, emitted power is concentrate in certain direction directed by the antenna.

The antenna gain G is defined as the ratio of flux density in a specific direction at a distance and the flux density of the ideal isotropic antenna used as a transmitter. The effective area is considered at the receiver end in order to calculate the amount of electromagnetic energy received. Considering Ar as the effective area of the receiver antenna, calculating the power at receiver given as in Equation 2:

$$Pr = S \times Ar \tag{2}$$

Similarly, the effective area, Ar of the receiving antenna can be drawn from the gain Gr and given as:

$$Ar = \frac{\lambda^2 \times Gr}{4\pi} \tag{3}$$

Where, λ = wavelength of transmitting signal
Gr = Gain at the receiving end of the antenna

Table 1: Antenna classification based on required properties

S.N	Antenna Type	Characterstics
1	Mono-Pole Antenna	Polarization : Linear Half-power beam width: 45×360 Gain : 2-6 dB at best Frequency limit: None
2	Dipole Antenna	Polarization : Linear Half-power beam width: 80×360 Gain: 2 dB Frequency limit: 8 GHz (upper)

As very common, Dipole antenna is simple, reliable and sufficient within many working areas. For a small satellite, it is appropriate to choose the dipole antenna of λ /2 length also called half dipole antenna. These antennas don't work wisely below 2MHz frequency due to wavelength constraints.

$$\lambda = \frac{2C}{f} \tag{4}$$

Where, C = speed of light and f = frequency of operation

The idea of using measuring tape as an antenna is not new. Previously radio tape were also used as an antenna. It is similar to the idea of OPAL. The launch and deployment of picosatellites from the Stanford University in February 2000 was known as OPAL microsatellite project [12]. The measuring tape is attached as two independent dipole components located at the end of the CubeSat. It can work in UHF band.

It has simple structure so it has predominant choice over other antenna options. Dipole in normal behavior do not exhibit circular polarization unless jumbled together with phase shifting. It also delivers narrow band channel and low antenna gain. It also supports reasonable width of bandwidth. The measuring tape as long durability and can withstand different weather conditions. So it's an ideal type of antenna for selection. Antenna is the interface that is used for transmitting or receiving radio waves for communication purposes. In transmission, electric current is passed through the antenna terminal and the antenna radiates the energy in the form of electromagnetic waves. In case of reception, the antenna receives a fraction of power density of the radio wave and produces electric current at its terminal ends which was then amplified [13].

Table 2: Dipole Antenna Classification

Parameters	Short-Dipole	Half-Dipole
Length	L ≪ (λ/2)	L = (λ/2)
Impedance (Za)	Greatly Capacitive	(40-80) ohm
SNR	2:1	2:1
Directivity	1.8 dBi	2.1 dBi
Polarization	Vertical, Horizontal	Vertical, Horizontal
Beam width	85 × (360)	85 × (360)

Communication board deals with the communication between ground station and satellite situated at 45ft height. Since, this communication board can be used as a transceiver, one board is used at PocketQube and another is used at Ground Station. There are several communication board such as RFM98w, RFM26w etc. It works in SPI and serial protocol.

4.2. Payload System Design

Structure acts as a platform. It maintains the structural integrity of the system. It also helps in mechanical load bearing. Its orientation is to thruster and conductive path. It also shields weak and prone OBC against radiation. The structure selection criteria for the material are strength, mass, machinablity, cost, availability of material and magnetic properties. The magnetic field of earth interacts with the magnetic material so it may affect the attitude of the satellite.

Figure 3: Subsystem Structure

OV2640 Camera Module produces 2MP JPEG image

Table 3: Battery Specifications

Battery Types	NiCad	Li-Ion
Voltage/Cell	1.2	3.6
Density	45-80	150-250
Charge Temperature	0 to 45C	0 to 45C
Discharge Temperature	-20 to 65	-20 to 60
Notes	Ok to Discharge	Cell protection is needed
Approx Weight of 150WH	2.5kg	0.8kg

in compressed size. The camera chip is a low voltage CMOS image sensor that provides the functionality integrated single-chip UXGA (1632×1232). It has high sensitivity for low light operation. It contains two 10 bit (A/D) converter. It produces 6mb of data i.e. 1 byte per color however the image size is small due to JPEG compression. It works on SPI and I2C protocol. The camera module contains CMOS Sensor which is very effective then CCD Sensors because CMOS Sensor uses 2.8 to 5v of power where CCD uses 12 to 15v which is not effective in Small satellites. CMOS also cope with blooming effect in the image due to high intensity of incident light on the filter.

Electrical Power Subsystem (EPS) is a fully autonomous system which is capable of producing power which is sufficient to produce and distribute it to various subsystem of the system. Satellite is also an EPS system. If the power obtained from the power supply is greater than the consumed power, it should be able to charge the battery. If the power consumed by the subsystems of the satellite is more than the power produced, the battery should be able to provide the power for the system. If any fault or malfunction occurs in the system such that the subsystem consumes more than the desired current, the EPS should be able to limit the current to prevent overload of the system.

Previously, untill 2000 AD, NiCad battery was popular. In recent years, Lithium Ion batteries are common in use due to its properties of large energy density and excellent low temperature performance. In general, the battery capacity dwindles with flutuation in temperature. Hence, the battery capacity of the installed battery needs to increase for long lasting performance [14]. Hence we have implemented the Lithum Ion rechargeable battery which gets charged when the solar panel is oriented in such a way that it draws maximum energy from the sun. The Li-Ion battery degrades with life and usage. It needs cell balancing while charging multiple cells. The Li-ion battery cannot be fully discharged. The Solar filter

Figure 4: Solar Panel Integration

which is embedded on the four sides of the system is passed through balance battery. The balance battery always passes same amount of voltage through it which maintains the efficiency and performance of the system. It controls overloading or deficiency of power. The power passed from balance battery is passed through the chargeable battery which powers the whole PocketQube. The power from the battery is distributed throughout the system through a distribution board. The distribution board distributes the power to camera module, radiation sensor, microcontroller and telemetry.

5. Result and Discussion

The section demonstates the result acquired during the experimentation with different components.

5.1. PockectQube Structure

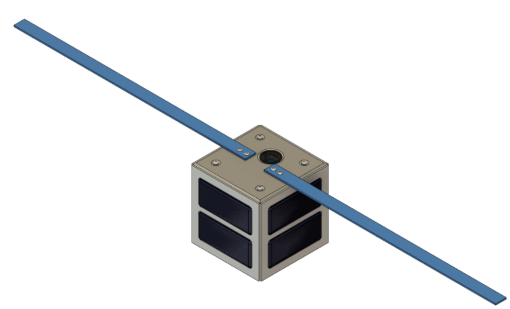

Figure 5: PocketQube 3D modelling

Basend on theCubeSat standard the modular structure

Table 4: Reading Sensor Data

SN.	Sensor Readings	Sensor Data
1	Acceleration	X = -652, Y = -436, Z = 7610
2	Gyration	G_X=732, G_Y= -337, G_Z=236
3	Magnetometer	M_X= 41, M_Y= 37, M_Z= 134
4	Altitude	45 ft
5	Light Intensity	1.67 lux
6	Pressure	871.44 hPa

of the satellite is built. The design accomplish with the multiple layer of the mounting configurations with the maximum flexibility in the design process. The multilayer PCB boards are stacked together in order to make the satellite more compact structure.

5.2. Reading Sensor Data

We have used different sensors such as Accelerometer, Magnetometer, Intensity, Pressure, and gyroscope. These sensors help in balancing the CubeSat as well as provides the necessary pressure and temperature measurements. The outputs of each sensors are provided below:

5.3. Received Image Analysis

When the image is received to the ground station, it is analyzed at the ground station using QGIS software. The raster tool of the software is used to calculate the NDVI index of the image. The NDVI index help to monitor the situation of the vegetation on the captured region of earth surface.

Image captured by the camera is assumed as: The NDVI

Figure 6: Tripureshwor Area Image

of this region of Tripureshwor area is calculated as: The image shows the vegetation condition of the area. The different color palette shows whether the land is dry or filled with vegetation. The figure above shows the red

Figure 7: NDVI Calculation plotted Image

color as low presence of vegetation whereas the blue color shows the presence of vegetation in the respective area.

NDVI Calculation using Raster Library in Python of CubeSat Image: The two landsat image is used in order

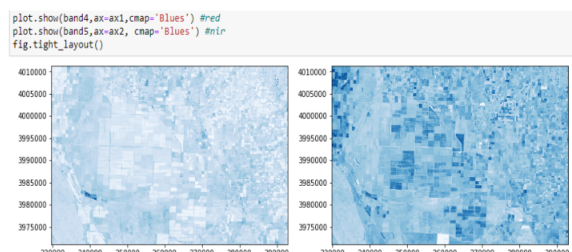

Figure 8: Landsat Image

to analyze the condition of vegetation in the area. In the figure above, the NDVI is the graphical indicator that is analyzed to visualize remote sensing measurements. Green vegetation utilizes the red light for the photosynthesis process and emits the NIR rays. The dead vegetation utilizes the NIR rays where as it reflects the Red light. Hence, NDVI of certain geographical area can be calculated from above assumption. NDVI is calculated as:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{5}$$

NDVI varies from -1 to +1. The value close to +1 indicates the presence of healthy vegetation whereas values close to -1 indicates the desert area, lacking the good quantity of vegetation.

After Calculating NDVI the image is shown as in Figure 9:

Here the dark green area indicates the presence of healthy vegetation.

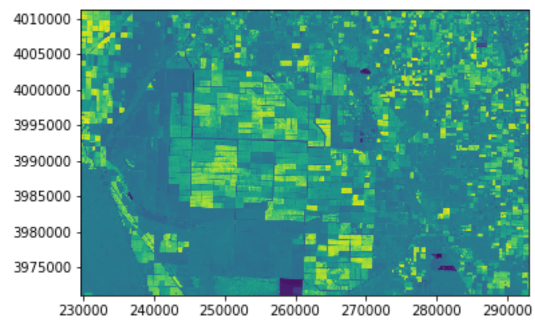

Figure 9: NDVI of the Landsat image

6. Future Enhancement

The orientation control of the CubeSat has been a major challenge for the engineers in recent years. Proper orientation control can be implement in order to magnify the gain from the solar panel, by facing on a right orientation to the sun. Advanced RFM-xxx modules can be used to transmit data at higher rates over larger distances between the transmitter and receiver. Retractable antenna system can be implemented in order to make the structure more compact and flexible. Transmission of video files from the payload to ground station also can be implemented. Video files consists of higher file size hence the data rate of sending the files to the ground station need to increase.

7. Conclusion

The field of CubeSat development campaigns are getting popular in recent years. Universities are continuously encouraging the students for the space research and exploration. Different research campaigns are been conducted with the help of CubeSats. CubeSat are the technologies that provides the maximum efficiency with low cost during the construction of the structure and selecting the economical payload.

We have also been successful on realizing the vegetation condition on the earth surface which eventually helps in analyzing the chance of forest-fire in the dense decayed vegetative condition by analyzing the sudden change of vegetation conditions in forest area by continuous monitoring and surveillance of the fire prone forest. We were successful on analyzing the deforestation in the specific geographical area which can be surveyed and can be used to make the authority aware about it.

References

[1] Messier D. Tiny cubesats getting bigger role in space[M]. Space.com, 2017.

[2] Satyal U. Nepal's first satellite, nepalisat-1, launched[M]. Kathmandu: The Himalyan Times, 2018.

[3] Observatory N E. World of change : Global temperature[J]. 2015, 21.

[4] Lucy M. The first photograph of earth taken from space[M]. Adelaide: Cosmos Magazine, 2017.

[5] Paudel N. Nepal's first ever satellite launched into space[M]. Kathmandu: The Kathmandu Post, 2018.

[6] Hywel. Cubesat cameras and optical payloads for small satellites on the global marketplace[M]. Satsearch, 2020.

[7] Laboratory J P. Jpl mission breaks record for smallest satellite to detect an exoplanet[M]. California: California Institute of Technology, 2020.

[8] Knapp S S M. Demonstrating high-precision photometry with a cubesat: Asteria observations of 55 cancri e[J]. Arvix, 2020, 23.

[9] NASA. Elana 41 mission[M]. NASA, 2022.

[10] of California U. Qubesat[M]. Berkeley: NASA, 2022.

[11] Hamrouni C. Design and prototype of a flight microstrip antennas for the pico satellite erpsat-1, istanbul: Ieee[J]. 2009.

[12] Heidt M H. A new generation of picosatellite for education and industry low-cost space[J]. Digital Commons, 2000, 5: 19.

[13] Knight J C. Safety critical systems: Challenges and directions[M]. in Research Gate, 2002.

[14] Sebestyen S F N G A C G. Low earth orbit satellite design[M]. Springer Science and Business Media LLC, 2018.