CUBE SATELITE CONCEPTUAL DESIGN

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Abstract- Even though CubeSat designing is still a new field in Sri Lanka, recent times the interest towards smaller satellites is being improved and becoming commercialized throughout the world. The cheap and simple design capabilities and availability of low-cost launching facilities are the main reasons for this popularity. This report is a comprehensive guide to design small scale, functional CubeSat. The structure and subsystems are clearly explained with appropriate modules that can be used for necessary functions of the systems. The techniques and methods used to obtain desired objectives are clearly explained with reasons. Structure is basically of aluminum and hardened to withstand the harsh environmental conditions. OBC and other peripheral components are chosen considering the unique environment condition and the operating requirements of the mission. Controlling mechanism uses a PID arguments which are not mentioned in this work. But the operating principles are explained in detail for a clear understanding. Communication with ground station is been implemented with LoRa technology. EPS uses separate algorithm to turn the CubeSat into different modes in accordance with the current task. An ambient light sensor is used as the payload to get luminous intensity of the Sun. This data is collected in expectation of supporting the weather forecast of Sri Lanka. The work has a theoretical background rather than a practical implementation.

Index Terms- Altitude determination and controls, Communication, CubeSat, Electrical power regulation, On board computer, Satellite structure, Solar light intensity sensor

I. INTRODUCTION

We are a group of Engineering undergraduates from University of Peradeniya. We had the opportunity to attend the Cube Satellite workshop series organized by SEDS Pera in 2021. We got a comprehensive understanding about these small satellites and got amazed by the feasibility of building a one with the current technology within Sri Lanka. The seedling of our inspiration to build a CubeSat was developed with the Ravana-1. With this competition we were able to nourish ourselves with knowledge of different technologies and best practices which can be applicable in many areas that we are about to follow. This is our proposal report on developing a complete, functional CubeSat with the technology currently available in our country. We hope this will lead to another successful CubeSat launch under the name of Sri Lanka.

II. STRUCTURE SUBSYSTEM (STR)

A. *Role of the structure subsystem.*

Structural subsystem is the skeleton of the CubeSat. It provides a platform to mount all the other components. It should bear all the loads. This is also the part that interact with the launch vehicle.

B. *Proposed materials.*

As the primary material for the structural subsystem the choice was aluminum. It is a light weight yet strong metal with good corrosion resistance. AA 6061, which is the most commonly used aluminum alloy in aerospace industry seems suitable for the frame. This alloy has very good machining capability and it is suitable for welding purposes too. That is why AA 6061 is widely used for making wings and fuselages of aircrafts.

Physical Properties	Metric	English	Comments
Density	2.7 g/cc	0.0975 lb/in³	AA; Typical
Mechanical Properties			
Hardness, Brinell	95	95	AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop	120	120	Converted from Brinell Hardness Value
Hardness, Rockwell A	40	40	Converted from Brinell Hardness Value
Hardness, Rockwell B	60	60	Converted from Brinell Hardness Value
Hardness, Vickers	107	107	Converted from Brinell Hardness Value
Ultimate Tensile Strength	310 MPa	45000 psi	AA; Typical
Tensile Yield Strength	276 MPa	40000 psi	AA; Typical
Elongation at Break	12 %	12 %	AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break	17 %	17 %	AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity	68.9 GPa	10000 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Notched Tensile Strength	324 MPa	47000 psi	2.5 cm width x 0.16 cm thick side-notched specimen, K_t = 17.
Ultimate Bearing Strength	607 MPa	88000 psi	Edge distance/pin diameter = 2.0
Bearing Yield Strength	386 MPa	56000 psi	Edge distance/pin diameter = 2.0
Poisson's Ratio	0.33	0.33	Estimated from trends in similar Al alloys.
Fatigue Strength	96.5 MPa	14000 psi	AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen
Fracture Toughness	29 MPa-m½	26.4 ksi-in½	K_{IC}; TL orientation.
Machinability	50 %	50 %	0-100 Scale of Aluminum Alloys
Shear Modulus	26 GPa	3770 ksi	Estimated from similar Al alloys.
Shear Strength	207 MPa	30000 psi	AA; Typical

Fig. 1. Properties of AA 6061 alloy

To protect from harsh operating environment, the structure should be anodized. We are also planning to use Aluminum polyimide for multi layered insulation.

C. *Thermal Controls.*

Most of our proposed components work on range of -40 to 80^0 C. So, we need highly efficient active and passive thermal regulators.

Around the Aluminum frame we are planning to coat multi-layer insulation blankets that can act as first surface mirrors. The reason choosing first surface mirrors over second surface mirrors is because they reflect more solar radiations than the other. The surface will contain an aluminum coating and polyimide film will be the substrate. This is because of polyimide's ability to resist the high temperature environment and as it is the common choice for these types of activities in other instances. For inner layers of insulation blankets, films will be coated on both sides to take advantage of aluminum's low emittance rate.

For active thermal control a resistance temperature detector is used to measure the inside temperature. Resistance based heater will be implemented as the internal heating mechanism and a Peltier chip is used as the cooling mechanism.

D. *Manufacturing costs, budget and feasibility.*

Aluminum is a readily available cheap material. It has a high machinability. This is also one of the reasons why we chosen Aluminum. The plan is to make 6 square frames and weld them together to make the cube. Then it will be anodized and the coating will be applied after assembling all the parts to the structure. We are designing a 1U cube satellite and total approximated mass of the system is around 500g.

TABLE I. MANUFACTURING COST OF THE STRUCTURE

Item no.	Manufacturing Cost		
	Description	*Quantity*	*Cost ($)*
Item1	AA 6061 aluminum plate	1	6.00
Item2	Polyimide	1	5.12
Item3	Machining		50.00
Item4	Labour		20.00
Item5	Overheads		25.00

III. ON BOARD COMPUTER (OBC)

A. *Role of the OBC.*

All the subsystems should be monitored and controlled for proper functionality. This is done by the OBC. OBC acts as the brain of the cube satellite and ensures the mission is fulfilled throughout the lifespan of the CubeSat.

B. *Micro-controller proposed.*

The micro-controller we planning to use is a Atmega328p by Atmel. The main reason for choosing this is because it is a low power considerably high-performance microchip which is ideal for the tasks it needed to perform. It works well in 3.3V logic level, which is the expected level we are going to use in most of the sensor modules. It has a built in ADC and a EEPROM that is hard to find in other alternatives of the same range.

Parametrics

Program Memory Type	Flash
Program Memory Size	32
CPU Speed (MIPS/DMIPS)	20
SRAM (KB)	2,048
Data EEPROM/HEF (bytes)	1,024
Digital Communication Peripheral	1-UART, 2-SPI, 1-I2C
Capture/Compare/PWM Peripheral	1 Input Capture, 1 CCP, 6PWM
Timers/Counters	2 x 8-bit, 1x 16 bit
Number of Comparators	1
Temperature Range	-40 to 85deg
Operating Voltage Range (V)	1.8 to 5.5V
Pin Count	32
Low Power	Yes

Fig. 2. Atmega328p micro-controller specifications

Arduino IDE can be used to program the micro-controller which is another plus point as we do not need to hard code it in assembly. Since the Arduino boards also use this, huge community support which we can take advantage from will be a tremendous help in debugging phase.

C. *Functions planning to perform with the OBC.*

OBC is the main processing unit of the system. So, most of the controlling parts are expected to be handled through the system.

Telemetry and payload data should be processed and stored until the they are ready to send. Telecommands should be processed and execute the desired outcome. We are planning to include an error checking and correction algorithm to ensure environmental conditions has not messed up with signals. Decoding and encoding of the packets that are about to transmit is also a function which we are planning to take out of the OBC.

Status of the satellite should be measured continuously and be able to initiate backup procedures whenever a fault in the system is detected. Other subsystems should be monitored and reset if a system went unresponsive. Altitude determination and control is also handled by the OBC.

As an assisting component, we plan to a MAX6369 watchdog which will reset the OBC if the computer gets hung up.

D. *Memory / EEPROM*

Atmega328p micro-controller has a 32kb of flash memory, 1kb of EEPROM and 2kb of RAM. We are only interested in the payload data of near Sri Lanka space. So, the OBC does not need to store heap of telemetry and payload data to be sent to the ground station. The required data can be collected and transmitted in real time. Therefore, the 1kb EEPROM is sufficient for our task. No need of external memory extensions.

IV. Attitude Determination and Controls (ADCs)

A. *Role of the ADCs.*

Altitude determination and controls system is responsible for controlling and maintaining the orientation and the desired altitude of the cube satellite.

B. *Controlling mechanism.*

For detumbling and orientation control, we are using 3 electro magnets on the 3 axes to generate magnetic torques. Since our payload is occupied with measuring solar luminous intensity, the sensor needs to turn in the direction of the Sun. So passive control is not sufficient. No need of flywheels since no rapid turns are necessary. The direction of the Sun is detected using voltage differences of solar panels. Using magnetic torque, the sensor is directed towards the Sun. Gyro sensors are used to measure rotation rates and acceleration.

A magnetometer is used as the altitude sensor. Magnetic field decreases with altitude. Since we are in a low orbit these flux densities can be measured.

The altitude control system is designed to be active only in Sri Lankan space since we are calculating the weather forecast of Sri Lanka. In other locations the turning mechanism acts as a dormant system unless specified by tele commands in special situations.

C. *Components planning to use.*

Adafruit 9DOF BNO055 sensor which has both gyro and magnetometer is our choice for the altitude control. Although accelerometer has some delay in responding gyro sensor can compensate for that and aid in controlling the CubeSat. It is sufficient as the cube does not need rapid motions and accelerations.

V. Electrical Power Subsystem (EPS)

A. *Role of the EPS.*

This is the part where power is produced and distributed to other parts/operations of the satellite. When the power consumed by the subsystems are greater than the obtaining power then the battery should be able to give power. otherwise, where the obtained power is higher, then it should be able to charge the battery.

B. *Solar cell selection and justifications.*

Main part of the power system is the solar cells. According to our goal and the procedure, it is more suitable to use the 32% Quadruple GaAs solar cell. The eclipse time is around 35 min. Therefore, in a short period the batteries should be charged properly to the required level. We are also planning to use electromagnets to control the direction of the sat. So, it also consumes more energy other than using permanent magnets. Reason is in our case we are planning to use a light intensity sensor. It is required to face the sensor directed to the sun. Electromagnetic systems are used to maintain that purpose. This sensor part also consumes additional energy.

By considering the above reasons, it was decided to use a high efficiency solar cell (32% Quadruple solar cell).

Dimensions, efficiency, power generation of the cell of this cell is mentioned below. Those details are taken from the data sheet of the cell.

32% Quadruple Junction GaAs Junction Solar Cell
Type: QJ Solar Cell 4G32C - Advanced

Design and Mechanical Data

Base Material	AlInGaP/AlInGaAs/InGaAs/Ge on Ge
AR-coating	TiO_x/Al_2O_3
Dimensions	40 x 80 mm ± 0.1 mm
Cell Area	30.18 cm^2
Average Weight	≤ 1780 mg (*≤ 2600 mg)
Thickness	110 ± 12 µm (*150 ± 20 µm)
Contact Metallization Thickness (Ag/Au)	4 – 6.2 µm

*available alternative version

Electrical Data (typical)

		BOL	5E14	1E15	3E15	1E16
Average Open Circuit V_{oc}	[mV]	3451	3292	3227	3120	2955
Average Short Circuit I_{sc}	[mA]	457.6	453.3	451.5	423.8	365.1
Voltage at max. Power V_{mp}	[mV]	3025	2866	2793	2700	2581
Current at max. Power I_{mp}	[mA]	433.5	428.0	423.8	394.0	320.9
Average Efficiency η_{bare} (1367 W/m²)	[%]	31.8	29.7	28.7	25.8	20.1

Standard: PS_4G32_PTB_2016-09-13; Spectrum: AM0 WRC = 1367 W/m², T = 25 °C @fluence 1MeV [e/cm²]

Fig. 3. Properties of Quadruple GaAs solar cell.

According to the instructions of the data sheet of the solar cell, it is necessary to use an external bypass diode protection.

C. *Solar Array configuration.*

In our plan we are hoping to use body mounted solar panel configuration. Because in deployable configuration, the solar panel should always be directed to the sun. We only use electromagnets to change direction of the satellite when only in data measuring target points. As an example, we only needed to get the intensity when the satellite is above Sri Lanka. Therefore, only at that point it was needed to control the direction of the satellite.
It is necessary to control the excess current in the circuit. For that a current power monitoring circuit is chosen. INA219 can be used for this purpose.

D. *Battery selection and justifications.*

Li-ion batteries are used to store the energy obtained in the solar cells. Nominal voltage is 3.7V. Operating temperature is from 0 to 45^0 C. To maintain the operating temperature, Hearts and power dissipation systems are stored in EPS.

VI. Communications Subsystem (COMMS)

A. *Role of the COMMS.*

Communication subsystem is responsible for transferring telemetry and payload data to the ground station and receive any telecommand given from the ground station.

B. *Types of communications proposed.*

Since the satellite will be orbiting in around 500km altitude, we have to implement communication system that can surpass disturbances in the high altitudes. The encrypted data should be converted to Morse codes inside the micro-processor. These signals should be received and modulated by a transceiver and transmitted through the antenna. For this we thought of using LoRa technology.

C. Link Budget Analysis.

We are hoping to use UHF frequencies for the communication. Since turning CubeSat antenna towards the ground station is a complex task and it will consume considerable power, we are planning to use an omni directional antenna. It will be able to transmit data even with little tumbling.

For the ground station we are expecting to use a directional helical antenna with circular reflector. As we are not restricted on power level, our plan is to compensate for the CubeSat transmission power limitations with a high gain antenna on the ground station. 2 motors will be used to track the direction and a matching polarization will be applied using another motor to retain the quality of receiving data.

D. Communication microchip selection.

Among the LoRa supporting transceivers, RFM98W is what we are going to use. It works on 3.3V and it has FSK modulation capability which we are going to use for our transmission. 300kbps data rate is sufficient for the data link.

E. Regulations applicable when communicating with the satellite and reserving the frequency.

The frequency we are using must be in accordance with International Telecommunication Union (ITU) regulations. The Sri Lanka Telecommunication Regulatory Commission (SLTRC) is the responsible body for ITU coordination. A detailed report mentioning mission and requirements should be handover to the SLTRC. After doing thorough assessment with the ministry responsible for defense, they will coordinate us with the ITU. Since this will be a long-term process, we will create API and submit it to the SLTRC and request the frequency and bandwidth alongside with developing CubeSat.

VII. PAYLOAD AND MISSION

A. Type of the payload.

As the payload a solar luminous intensity sensor is chosen. We believe it will measure an important low earth orbit environmental factor that can used to support the weather forecast of Sri Lanka.

B. Components planning to use.

As the light intensity sensor, a Adafruit BH1750 ambient light sensor will be used.

There are several reasons for choosing this particular sensor over other ambient light sensors. Since we are operating in a harsh environment, we need a high build quality sensor. Adafruit BH1750 sensor has specific characteristics which seem promising in working in the environment. Usually, the Sun provides illumination ranging from 32000 to 100000 lux. The sensor's range is 1 – 65535 lux. But by using an optical window, the range can be improved to 0.11 to 100000 lux. Because of this function, the sensor is suited to achieve our target.

●Absolute Maximum Ratings

Parameter	Symbol	Ratings	Units
Supply Voltage	Vmax	4.5	V
Operating Temperature	Topr	-40～85	℃
Storage Temperature	Tstg	-40～100	℃
SDA Sink Current	Imax	7	mA
Power Dissipation	Pd	260※	mW

※ 70mm × 70mm × 1.6mm glass epoxy board. Derating in done at 3.47mW/℃ for operating above Ta=25℃.

●Operating Conditions

Parameter	Symbol	Ratings			Units
		Min.	Typ.	Max.	
Vcc Voltage	Vcc	2.4	3.0	3.6	V
I^2C Reference Voltage	VDVI	1.65	-	Vcc	V

Fig. 4. Properties of Adafruit BH1750

C. Data Processing

We are extracting the light intensity data from the surrounding. This data is sent to the ground station where it will compare with the intensity at ground level. These data will be used to assume the interferences in the sky, cloud density and other phenomena which can caused loss in luminosity. Using an algorithmic model, the information will be corelated with the weather condition of that time. The information extracted from it will help to predict the weather forecast.

CONCLUSION

The report elaborates on designing a CubeSat with readily available components in the market. Although this can be used as a guide for an actual model, when we are designing there should be several testing phases to come up with the best CubeSat model for a specific mission. This work has a theoretical basis and some modifications may require in practical application of the process. Furthermore, there is room for more innovative solutions. We believe this work will inspire CubeSat enthusiasts and will help them build their own model that will roam freely in Earth's orbit.

ACKNOWLEDGMENT

Orion Space, Madhyapur Thimi, Nepal

SEDS Pera, Peradeniya, Sri Lanka

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