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# Design and Development of Low Cost and Miniature Sun sensor for CubeSat

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***Abstract*---** **CubeSat's demand has exponentially developed in the last several decades for space research. In today's world, the entire communication, navigation, disaster management and weather forecasting is feasible because of the vast development in the space sector. The primary concern for the satellites orbiting in Low Earth Orbit (LEO) with a velocity of 25000 km/hr is stability; thus, Attitude Determination and Control Subsystems (ADCS) has implemented. A small-sized compact sun sensor is a part of ADCS which is designed and developed, having a significant role in 3 axes pointing accuracy and stability for payloads and antennas in microgravity. Sun sensor takes photons as the input from the outer space, processes the data by estimating the angular difference and gives the output to the actuators, thus has a significance in determining the orientation of a satellite in space. The designed sun sensor can withstand the temperature from -40 to 80°C. It has a total weight of 125 grams and a Field Of View (FOV) of ±40°. The sensor is designed using microcontroller STM32 and simulated using STM32CubeIDE and Proteus and SolidWorks software. Newly developed Sun Sensor can cover 160° spanning coverage as designed with high reliability. The designed Sun sensonis used for Sun navigation in Target Satellite (T-Sat).**

***Index Terms*— ADCS, CubeSat, Sun sensor, Low Earth Orbit, T-Sat**

## I. INTRODUCTION

The principal idea for the Attitude Determinations and Control Subsystems (ADCS) [2] is that the satellite payloads should have high pointing accuracy with a compact design. Many satellites point instruments towards their specific target depending on the application of the space mission. Some payloads can be either a camera, antenna or sensors [1]. The Sun sensor payload plays the most crucial part, which is relatively simple to design and can be configured. Sun sensor designed with Commercial-Off-The-Shelf (COTS) [3] tool by considering the cost and the accuracy for CubeSats.

Low Earth Orbit is the first orbit nearest to the Earth. Satellites like ISS and many academic and research purpose orbit about the Earth. They take approximately 90 minutes at a span of 200-2000kms to revolve. Satellites in the LEO do not trace a singular path around the Earth due to external factors.

The designed Sun sensor payload is implemented on the Target Satellite (T-Sat) that will be orbiting in the Low Earth Orbit approximately 500kms above the Earth surface. The speed of the same is 7.8kmps, which tends to hold the satellite from its orbit. External factors such as solar flares, the Earth's magnetic field and many more also contribute to deorbit the satellite. The payloads contribute to stabilizing the system for smooth functioning.

ADCS is used for finding the orientation and the stability of small-sized satellites like CubeSats, using different sensors. Three axes, namely Yaw, Pitch and Roll, are used for the correct adjustment of the satellite in microgravity can be found in outer space. Some of the other sensors used are the Star sensor, Earth horizon sensor, IMU, GPS, a three-axes magnetometer. The sensors attached to the satellite in the desired location are called 'payloads' in scientific terms. Sensors sense the data, take the input from the outer environment and then provide the data to the microcontroller for processing. The actuators do the needful changes in the position or direction as per the requirements. Along with the solar panels, external batteries like Li-ion store the power, as the solar-panelled power is not sufficient for a whole circuitry. The circuitry works on an external battery supply for the specific timespan when the satellite does not receive sunlight due to Earth's shadow(popularly known as 'eclipse'). From there, the energy is available to all the subsystems of the satellite to function. In the mechanical design of satellites, actuators such as magnet torque, reaction wheels and gyroscope play a crucial role. The sensors give the data input to the Onboard Computer (OBC) [2]. It then processes the data and passes the information to the actuators. The actuators rightly position the satellite in microgravity.

## II. THEORY

As space doesn't hold good for the atmosphere, there is no scattering of photons, thus makes it challenging to determine the Sun with the satellite revolving around the Earth with the velocity of 7.8km per second. The Sun sensor is designed and developed by considering the factors to navigate the Sun position. The sensor includes the photodetectors, which assimilate the photons received from the Sun only when the satellite oriented in a specific direction w.r.t the Sun. These photons are further converted into the voltage and fed to the OBC. The OBC performs the processing part, which compares the input with the preset data. After the processing accomplishment, OBC confers the output to the actuator to rotate in a fixed direction.

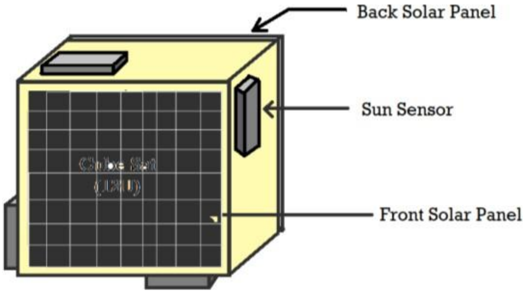

**Fig. 1: Placement of Sun sensor on Satellite**

Target Satellite (T-Sat) is a 12U cube-sized satellite with two opposite faces of the satellite occupying the solar panels. One of the panels will always face the Sun to provide the power to the circuitry of the Attitude Determination and Control System. Sun sensors are placed on the remaining four faces of the CubeSat [7]. Four sun sensors are placed on each side of the cube, as shown in fig. 1. After one of the Sun sensors detect the Sun, the actuator motor will rotate either in 90° clockwise or 90° anti-clockwise direction for solar panels to face the Sun, respectively.

Anyone side of the T-Sat will always face the Sun in space. This structure helps increase the accuracy and Sun detection time in ADCS.

### a. ADCS Block Diagram

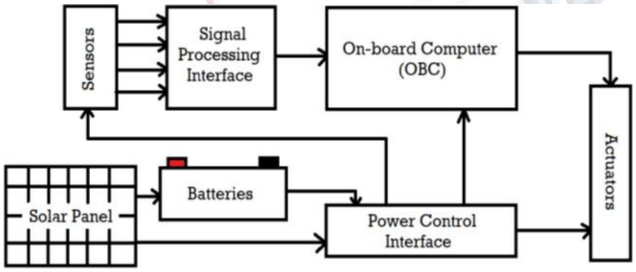

**Fig. 2: Block Diagram of ADCS**

Fig. 2 represents the block diagram of the ADCS. It shows the solar panels provide power to the whole system via the Sun sensors thus, be called a solar tracker. When the photons fall on the solar panel, it creates an electric field. This generated power is stored in the batteries to use in eclipse.

The power required for the microcontroller, sensor and actuator is different. The power control interface helps regulate power as per the need. The sensors block help to receive the information about the present location of the satellite in space and to detect the position of the Sun, the Earth etc. Four sun sensors will search for the Sun to collect the information for the signal processing interface.

A signal processing interface contains different processing units used for signal distribution and amplification of the signal. One of the blocks is the logic block, used to calculate the ambient light intensity. The next block is ADC, which converts the analog signal to the digital signal. The last block is Op-amp, which converts the photodetector's current into voltage.

The OBC is an onboard computer that is the brain of the system. The OBC itself is the microcontroller STM32 which helps the entire system to work correctly. This block will collect all the information from the sensors to provide the required output to the actuators to stabilize the system information from the sensors should be processed through the microcontroller. The satellite system should be stable to do so actuators are implemented for the movement of the satellite. In space, the satellite can rotate at the three axes yaw, pitch, and roll. There are actuators used to twist the satellite at these three axes. The sensors will first receive information about the present position of the sun. The sensors will pass the information to the OBS according to the sun's position. The microcontroller will send the signal to the actuators. The actuators will start rotating the satellite's solar panels faced towards the sun.

## III. MATH

$$d=h\tan(\theta) \tag{1}$$

$$|\theta| = 40^\circ \quad d = L/2 \tag{2}$$

$$|\varphi| \le 40^\circ \quad b = L = 2h \tag{3}$$

To measure a distance between 2 photodetectors, distance ‘d’ is calculated. The height h is a distance between the photodetectors and the top surface of the sensor casing. Angle ‘θ’ denotes the field of view (FOV) [8] made from the boresight. Boresight is the normal taken from the surface of the photodetector to compare the input. FOV is 40° in the design. For the $|\theta| = 40°$, the sensor distance ‘d’ should be equal to L/2 and for $\varphi \le 40°$, the slit length should be $b = L = 2h$. The width of a slit is as small as possible with a thickness of $c < a / \tan(\theta)$.

## IV. WORKING OF THE SUN SENSOR

### a. Sensor working :

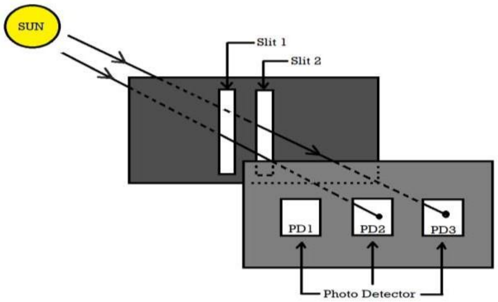

Fig. 3: Slits of the Sun sensor

Fig. 3 shows the working of the sun sensor diodes. Sun sensor comes in different designing styles, from which the easiest and more accurate is slit designing. Sun rays travel 151 million kilometres to reach the satellite orbiting around the Earth. The slits are such designed that only a concentrated bunch of photons should enter the slit. The placement of the slit is crucial.

In the designed Sun sensor, three slits are oriented vertically as the photodiode are horizontally placed at the bottom. The Sunrays enter 1st, 2nd or 3rd slit, depending on the FOV angle of the Sun concerning the boresight. When the Sun is towards the left direction of the boresight, the photons enter the slit 2 and 3, respectively. If the angle between the boresight and the Sun orientation becomes zero, the Sun sensor [9] can be said as perfectly oriented normally to the Sun. This case is the ultimate positioning of the satellite and further notifies the actuator to rotate 90° to let face the solar panels towards the Sun.

Three photodiodes are arranged in an array at a bottom of the sensor. After the photons fall on the photodiode, the sensor converts the photons to voltage using Sensor Processing Interface (SPI) as the output to microcontrollers (OBC). The microcontroller compares the voltage with the preset voltage and commands the actuators to rotate in 3 different axes to match the input voltage with the preset voltage.

### b. 3 axes rotation

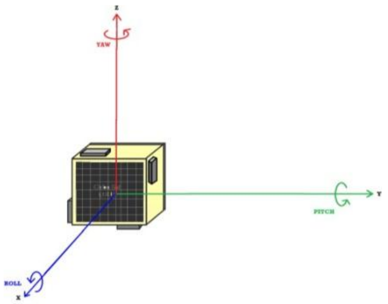

Fig. 4: Three axis in free space

Fig. 4 represents the three axes [6] in free space, namely YAW, PITCH and ROLL. Actuators are connected on the satellite walls to rotate the satellite clockwise or anti-clockwise direction depending on the Sun position in the free space [10]. The satellite keeps on turning in a particular spot until an external force stops. Thus works in the principle of 'Newton's first law of Inertia'.

### c. Photo detector sensor

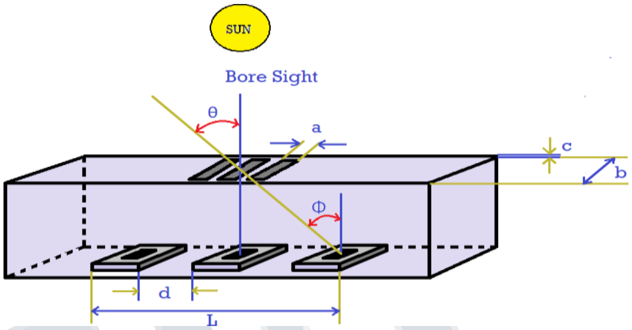

Fig. 5: Angle measurement and notation

In the design, with the distance 'd' between any two photodetectors. The three implemented photodetectors are on the surface of the casing. [4] The 'h' is the height of the upper part of the casing containing the slit. A slit 'a * b' is made on the top for the photons to enter through it [5].

## V. ADCS ALGORITHM

### A. Flowchart

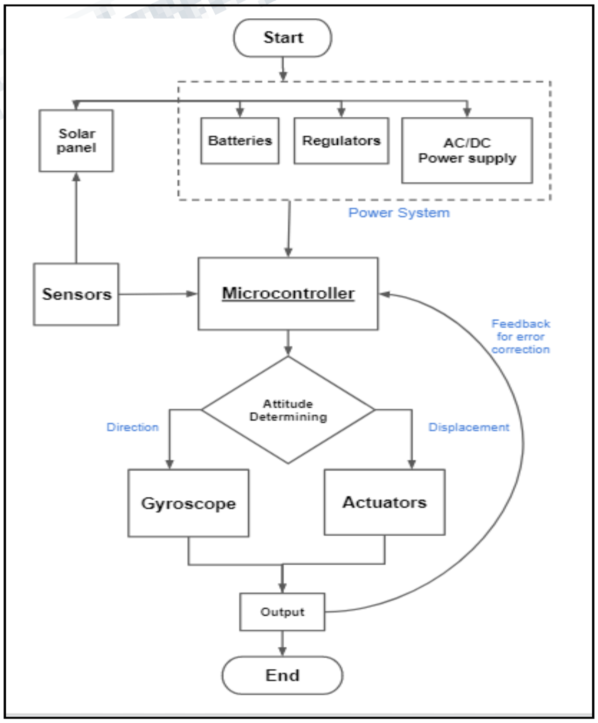

Fig 6: Sensor Flowchart

Fig. 6 shows the flowchart for the ADCS system. Initially, the system will get started. The microcontroller will receive the data from the Sun sensors. The microcontroller will compare the previous output with the existing one to find the difference. The microcontroller will send a command to the actuators to rotate the satellite clockwise or anticlockwise in yaw, pitch, and roll according to the output of the sun sensors. The gyroscope will help to understand the current position of the satellite then the satellite will rotate according to its desired location. The feedback loop is for error correction. Received power from a solar panel is then stored in the batteries, which will help the satellite receive power during the eclipse.

### B. Algorithm

1. Start
2. Take the output from photodetectors.
3. Compare with the preset output.
4. Command motors to rotate in clockwise / anticlockwise direction.
5. Again, compare output after the rotation of motors to the desired position.
6. Take input from the detector to check voltage difference.

### C. Comparison of photodetectors

**Table 1: Comparison of BH1750 and OPR5911**

| Sr. No. | Parameters | BH1750 | OPR5911 |
|---|---|---|---|
| 1 | Size | 13.9mm x 18.5mm | 17.75mm x 17.75mm |
| 2 | Weight | 0.039oz | 0.311428oz |
| 3 | External Components Requirement | Not Required | Required |
| 4 | Design | Simple | Complex |
| 5 | Measurement Variation | +/-20% | +/-22% |
| 6 | Operating Temperature | -140 ~ 185°C | -55°C ~ 125°C |
| 7 | Operating Voltage | 2.4V-3.6V | 2.5-3.5V |
| 8 | Current Consumption | 12nA | 20nA |

The above table represents the comparison between two photodetectors, BH1750 and OPR5911. By considering the parameters and the requirements for the space mission, BH1750 is prefered over OPR5911. With OPR5911, another supporting circuit needs to be attached, which increases the overall weight and size of the Sun sensor.

### D. Circuit Diagram

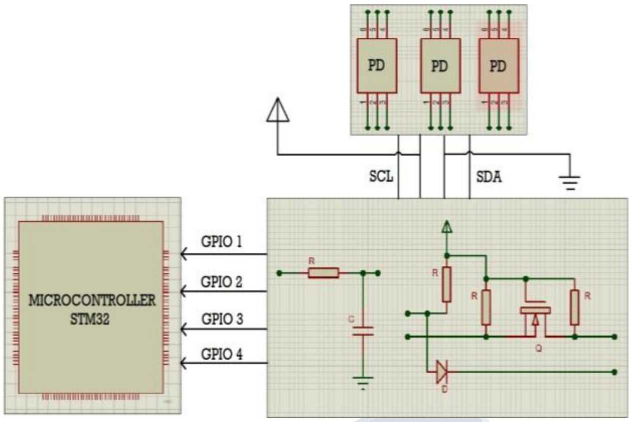

Fig. 7: Circuit flow of Sun Sensor

Figure 7 shows the circuit flow diagram of the Sun sensor to the On-Board Computer (OBC). The microcontroller plays a crucial role in receiving the input signal, processing the same and further sending the precessed signal to the actuators for the correction.

Photodiodes take in the photons and convert them to the voltage output. These signals are further sent to an amplifier to amplify the signal to fed the same in ADC. The amplified analogue signal is converted to the digital signal via ADC and passed to the 'Logic and I2C interface'. The received signal is processed and is made ready to further send through the I2C interface. SCL and SDA take care of the signal to send to the OBC. The voltage signal is thus sent further to the microcontroller to compare with the preset voltage. The OBC signals the actuators to rotate in 3 axes to match the input voltage.

## VI. PATH TRACED BY T-SAT

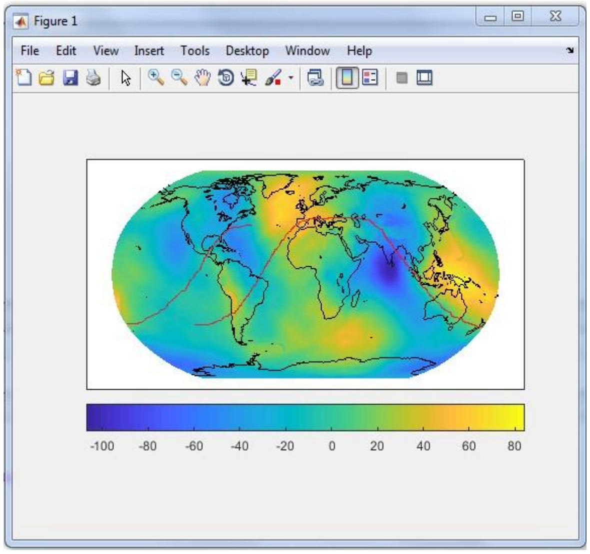

Fig. 6: MatLab simulated T-Sat LEO path

T-Sat (Target Satellite) will hold the designed Sun sensor payload weighing 125g each, launched in the Low Earth Orbit. Fig. 6 shows the MatLab simulated path traced by the T-Sat on the Earth with the red line. The sine wave on the right side represents the 1st orbital path, whereas the curve on the left is the 2nd orbit traced.

## VII. CAD MODEL

Fig 7: CAD model of the Sun Sensor

Fig. 7 represents the CAD Model developed on SolidWorks. The slits are at the top of the sensor and the connector RS232 on one side of the sensor. The electronic circuitry is compact inside the casing. The bottom space includes the nut-bolt fixing of the sensor on the satellite walls.

## VIII. TESTING

Fig. 8.1: Sun sensor interface with OBC

Fig. 8.2: Post detection image of the Sun

Figure 8.1 shows the Sun sensor prototype interfaced with the On-Board Computer, temperature display board and the externally connected solar panels in the testing room. The yellow coloured bulb acts as the Sun. As there is no scattering of light phenomena in the space, the testing room portrays as the darkroom. The OBC is a microcontroller that is responsible for every action taken by the actuators. The sun sensor is interfaced with the microcontroller to track the position of the bulb (Sun). Sun sensor sends the signal to the microcontroller. According to its output, the microcontroller sends the output to the actuators. The actuator rotates the satellite towards the Sun. The prototype works under extreme temperatures.

In the first figure, the Sun sensor initially is interfaced and is let to detect the Sun in space. Whereas, in fig. 8.2, the sensor detects the Sun. Voltage data is sent to the OBC to compare the input with the preset. The actuators rotate the satellite so that the panels face the Sun. Solar panel images the reflection of the bulb.

## IX. FUTURE SCOPE

The production of parts of ADCS is not making in India, which skyrockets the prices of ADCS when imported. Shortly, we can sell the ADCS product at a cheaper cost by manufacturing the same in our own country.

Future work is that we can interface more sensors increasing the accuracy of the position. We can implement this in other fields by changing simple software and hardware. It also can be helpful in the quality control of products before final dispatch.

Plenty of work remains before the ADCS is ready for launch. Most of the hardware design is completed, which means why future work should focus on software and testing. That is now possible with the ADCS Prototype.

## X. CONCLUSION

The designed sun sensor can withstand the temperature from -40 to 80°C. It has a total weight of 125 grams and a Field Of View (FOV) of ±40°. The sensor is designed using microcontroller STM32 and simulated using STM32CubeIDE, Proteus and SolidWorks software. Newly developed Sun Sensor can cover 160° spanning coverage as designed with high reliability.

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