Design of Simple Coarse Sun Sensors for CubeSat Attitude Determination

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Abstract: With the fast development in the area of CubeSat's application, higher are the requirements for precise altitude determination. This paper elucidates the advancement of cost-effective techniques to determine the sun-oriented attitude of a CubeSat. Sun sensors are the main components used for attitude determination in satellites by computing the sun vector. The sensor proposed in this paper can meet the higher accuracy requirement of CubeSat's attitude determinations. In this regard, this research proposed sensor attempts to bring down the power consumption and size factor thereby increasing the overall efficiency of the system. It also puts forward the calibration techniques which were carried out along with the database obtained.

Keywords: Active Attitude Determination, Light Array Sensor, Field of View, Photodiodes, CubeSat

I. INTRODUCTION

Attitude determination is one of the most widely performed routine tasks in any satellite system. The Attitude determination and control system (ADCS) achieves the task of acquiring, analysing and employing the data in safe manoeuvring and stabilization of the satellite. There are various techniques and devices available for performing the aforementioned task. Some of them include Gyroscopes, Inertial measurement Units (IMU), Star Tracker, Horizon Sensor, Magnetometer etc., but the most common one used is the Sun Sensor because of the perpetual nature of the sun in the Low Earth Orbit (LEO), the orbits for which most of the nanosatellites are designed for. Complete Attitude determination can also be done by only a combination of sun sensor and magnetometer data and applying the Algorithms. These methods could improve the efficiency of the attitude determination and utilise the components to its fullest potential.
Sun sensor is a device which determines the sun vector and routes this information to the On-Board Computer (OBC) which then commands the active actuators such as Magnetorquers and Reaction wheels.

In this paper, a single axis photodiode array sensor, TSL1401CL is used which is a prevalent line scan sensor. This sensor is effectively employed as a sun sensor, a previously unexplored area of its use. Other modes of attitude determination previously mentioned being very expensive, these sensors can be used as a frugal alternative for the attitude sensing purposes. This paper focuses on the design, fabrication, calibration and testing of this cost-effective sun sensors.

II. PRELIMINARY DESIGN

TSL1401CL is a 128x1 linear photodiode array sensor with 400 dots per inch (DPI) sensor pitch. It has a photosensitive area 3524.3 μm^2 with the interstice of 8µm between the pixels providing high density pixel count with full dynamic range. The light sensitive array is 8.064 mm x 1.8 mm long. The light rays striking on the pixels leads to charge generation and the amount of charge accumulated in the pixel during the integration time is directly proportional to the light intensity on it. The pixels with comparable charge densities are taken into account for measuring the angle of incidence. As shown in figure 1.

A slit of 100 micrometres is provided on the central axis of each array for the passage of light rays. As shown in figure 1. A setup of two photodiode arrays is placed perpendicular to each other with a T-shaped top view impression. As shown in figure 2.

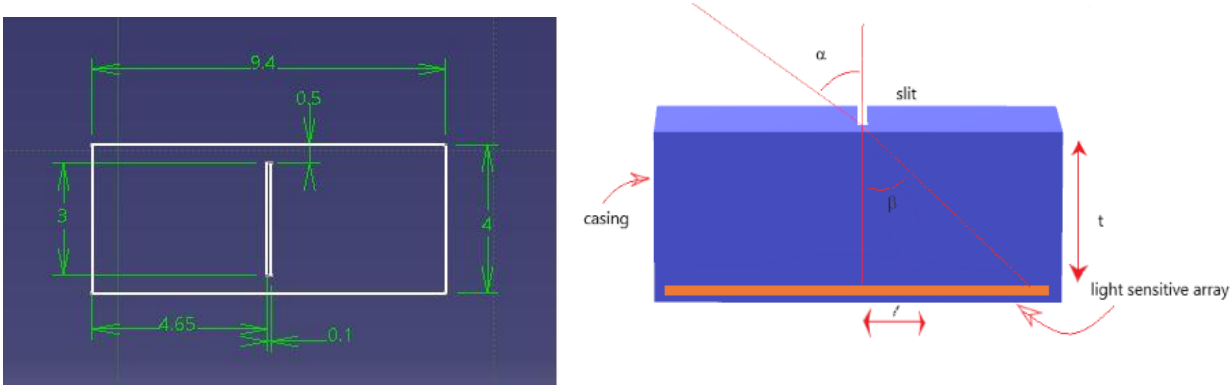

Figure 1: (a) Slit Design Drawing (b) 3D Slit Design

A. Formula for calculation of angles

$$\sin\alpha = n\sin\beta \quad \dots (1)$$

$$\tan\beta = \frac{l}{t} \quad \dots (2)$$

l-distance to the pixel, t-thickness of the slit

$$\beta = \tan^{-1}\left(\frac{4.032}{0.52}\right) \qquad \beta = 82.65^0$$

$$\alpha = \sin^{-1}(n\sin\beta)$$

$$FOV = 2 \times \alpha$$

$$FOV = 165.3^0$$

Field of View = 165.3 degrees

The inclination of the sun in both azimuth and elevation is found using (1 & 2)


Figure 2: T-shaped Configuration of TSL1401CL

B. Circuitry

The sun sensor, being I2C compatible, was controlled using an Arduino Uno microcontroller. As shown in figure 3. The sensor worked on a 5V power supply with analog matching of 0V for no light scenario, 2V to 2.4V for white level and a maximum of 4.4V to 4.7V for saturation level.

A total of 12 sun sensors were used and all the calculation of the angles was done based on multiplexing the results of pixel activation on each sun sensor and then computing the angles based on the maximum intensive area and sub-pixel determination ie. determining the most illuminated pixel in the most probable case of two or more pixels in the array being activated. The output of the attitude determination resulted in the sun vector angles being determined and then being routed to the On-Board Computer(OBC) for further processing.

The circuitry is as follows: -

Table 1:Connection Pin Configuration

Arduino UNO R3	TSL1401CL
5V	**VDD**
A1	**A0**
D4	**SI**
D5	**CLK**
GND	**2 GND PINS**

It was made sure that a bypass capacitor was connected closer to the device side as mentioned by the manufacturers.

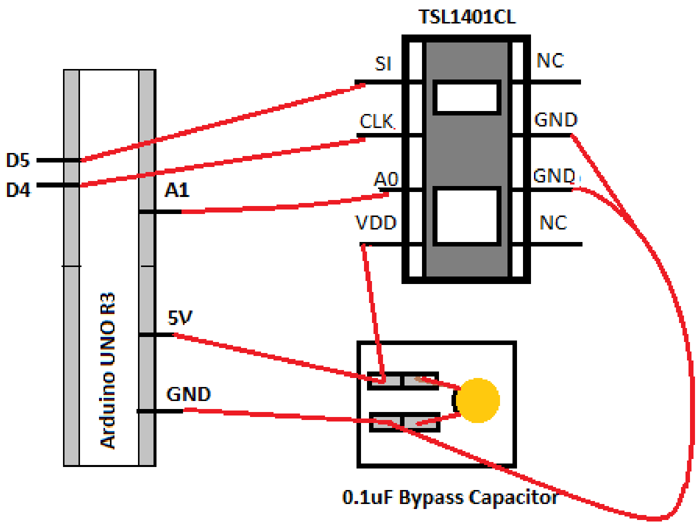

Figure 3: Connection to Arduino UNO R3

C. Calibration

The sensors were calibrated by a technique designed and realized during the research process. The method involved fastening the sensor to a rigid support. A semi-circular slit was cut on side of the setup made of wood and was placed perpendicular to the sensor. As shown in figure 4. A laser beam was used to activate the photo diodes at various angles along the semi-circular slit and the corresponding activations of pixels were noted and were used to calibrate other sensors the same way.

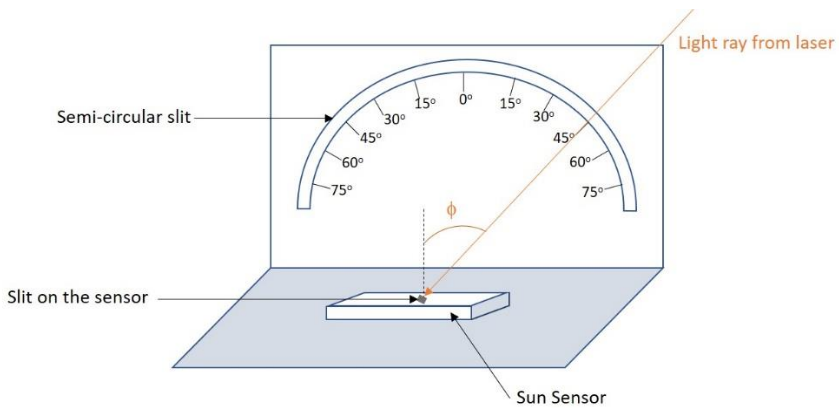

Figure 4: Calibration Setup

D. Integration with CubeSat

The sensors have to be placed in optimal position for the correct sensing of the sun vectors and the ideal position is the centre of each face of the satellite and also on the corner of the satellite on each face so that it does not affect the placement of the solar arrays for power generation.
The photodiodes being extremely sensitive must be protected from high energy radiation present in the orbit of the satellite to avoid any damage. The most prominent radiations present are electron radiation and gamma radiation along with the sunlight.
The gamma radiations being neutral in charge causes negligible deviations in the output characteristics of the photodiode while the electron radiation being highly energetic causes performance degradation of the photodiode which may lead to erratic and anomalous outputs from the photodiode and also reduction in the Field of view(FOV). To overcome these radiation effects the components can be radiation hardened and also a spectral filter has to installed to filter out the radiation other than visible light i.e. the photons from the Sun and not any other radiations.

III. CONCLUSION

A new type of Sunsensor based on MEMS technology has been described in this paper. This study has proposed a practical attitude determination of Nano-Satellites by using active light array sensors for an improved and cost optimized sun sensors by this method it can determine the desired state of ≈ 360 deg s^{-1} with and that the pointing error between the 3-axes is proposed to be less than 3^{o}.
In the next phase of this project is to fabricate the sensor and develop a new method to test the sensors on mounted scales for calibration and to incorporate it into RVSAT as per mission requirements and to maintain accurate accuracy of the sun sensors. Also develop a improved algorithm for the Sunsenor for On-Board Computer (OBC).

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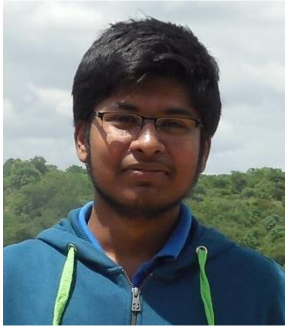

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