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NUSAT 1 Attitude Determination

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Abstract: This paper presents the methods for attitude determination using the static wide angle field of view sensors of NUSAT 1. Some supporting analysis and operational results are given. The system gives at best a crude attitude determination.

1. Introduction. NUSAT 1 was launched from a Getaway Special canister during May 1985. Its mission was to calibrate Air Traffic Control antennas. One factor that can help with the data reduction process is the satellite's orientation (see [3]). Therefore, attitude sensors were included in NUSAT 1.

Our purpose is to present the attitude determination process. Sections 2 - 5 give some of the analysis that went into creating a method for using the collected sensor data. In section 6 we present the process and give one example determination.

2. Overview. The shape of NUSAT 1 is a twenty-six sided polyhedron. Upon launch, the satellite was not given any initial spin, nor was there any attitude control. The tip-off angle was very small. Thus, it was initially earth oriented, i.e., rotating once per orbit with one face always towards the earth.

The attitude determination system consists of eight symmetrically located wide angle field of view (FOV) sensors. The direction of view of a sensor is the middle of one of the eight octants of a three dimensional coordinate system; sensor #3, in the first octant, has spherical coordinates $\theta=55°$, $\phi=45°$ (azimuth 45°, elevation 35°).

The sensors consist of "off the shelf" photo resistors located behind conical viewports of half angle 45° as shown in Fig. 1. The resistors are configured in a simple electric circuit so that the voltage drop across the resistor is available. This voltage reading is a maximum under no radiation and goes down in the presence of radiation. The main satellite computer can read and record the voltage at will. During prelaunch the sensors were set so that they read half scale when looking directly at the sun.

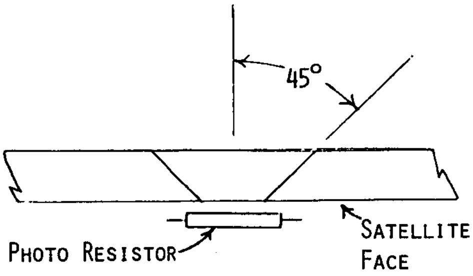

Fig. 1. Light Sensor

A sample set of data collected during one orbit on June 23, 1986 is contained in Fig. 2. For this orbit, the voltage was recorded at 40 second intervals over a period of 93 minutes. Sensor 5 failed and its data is not shown.

3. <u>Earth Brightness.</u> A major part of the operational analysis is the comparative effects of earth and sun light. If we assume that the earth is a uniform diffuse light source, then the brightness density ($w/m^2 sr$) of earth in comparison to the sun at the satellite's position is

$$B = (1/\Omega_e)\iint_S AI/2\pi\rho^2 \, ds$$

$$= (AIr_e/2\Omega_e(r_e+a))\ln(1+2r_e/a)$$

where A = earth's albedo,
I = power density of sunlight at the earth (w/m^2),

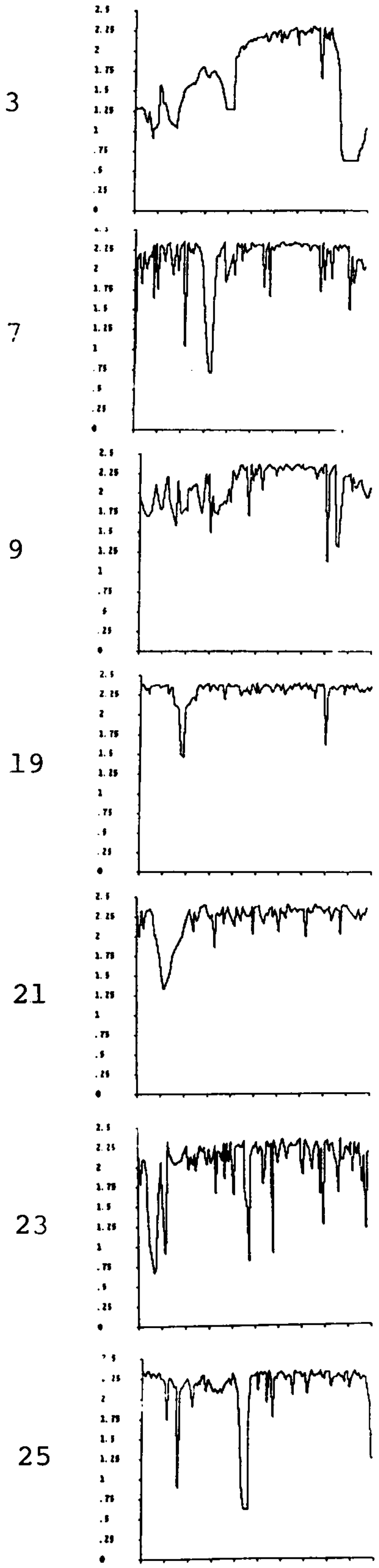

Fig. 2. Sensor data.

S = region of earth's surface that the satellite can view,
Ω_e = solid angle subtended by the earth at altitude a,
r_e = earth's radius,
and a = satellite altitude.

The relation of these parameters is shown in Fig. 3.

For NUSAT 1, we have a = 350km and Ω_e = 4.277sr. These values give B=.401 AI (w/m^2sr). The solid angle of a sensor is 1.84 sr, so that the power density of the earth light available to a sensor is .737 AI (w/m^2). Now the earth's albedo can vary between .05 for some soil and vegetation covered surfaces to .8 for some types of snow and ice or clouds [1] with an average of .3. Thus we have for the power density of the earth light available to a sensor

<u>A</u>	<u>Earth light power density</u>
.05	.03787 I
.3	.2271 I
.8	.5897 I

This analysis indicates that earth light will not have much effect on the recorded output. Recalling that full sun viewing will cause a reading of 1/2 down, earth light alone should only cause a reading of at most .3 down from maximum. On the other hand our model is not complete. It does not take into account any specular sun reflections observed in photographs of the earth. The earth is more like a uniform, diffuse, reflecting Lambert sphere [2] with an indistinct bright region midway between the subsolar point and subsatellite point.

4. <u>Viewing Conditions.</u> Two other important questions in the basic analysis are the number of sensors that can view the earth or the sun at a given time, and whether a sensor can view both the earth and the sun at the same time. These questions can be answered by considering the satellite lighting conditions. For this analysis we will think of the satellite as a sphere.

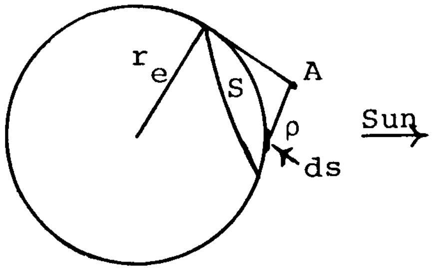

Fig. 3. Earth region visible at point A.

At an altitude of 350 km, the earth subtends an angle of 142° and the area of the satellite that can <u>not</u> receive light from the earth is a cone of half angle 19° centered about the zenith. The FOV is 45°, therefore the directions a sensor can point and <u>not</u> receive earth light form a cone of half angle 64° centered about the zenith. Half the satellite can receive light from the sun, but the 45° FOV reduces the set of directions in which a sensor can receive light from the sun to a cone of half angle 45° centered about the sun direction. Summarizing, a sensor receiving earth light is within 116° of the nadir and a sensor receiving sunlight is within 45° of the sun direction.

To determine the possible combinations of sensors receiving earth light or sun light a three dimensional physical model was constructed. The positions of the sensors were plotted as points on the surface of a sphere. Then small circles of radii 45° and 64° were plotted about each point. If the sun's direction is in a circle of radius 45° then that sensor can receive sun light. If the zenith is in a small circle of radius 64°, then that sensor can <u>not</u> receive earth light. The intersections of the small circles thus form regions that correspond to the combinations of sensors receiving sunlight or receiving no earth light. By analyzing the intersections, it was found that at least four sensors must receive earth light and at most seven sensors can receive earth light at a given time. Zero, one, or two sensors can receive sunlight at a given time.

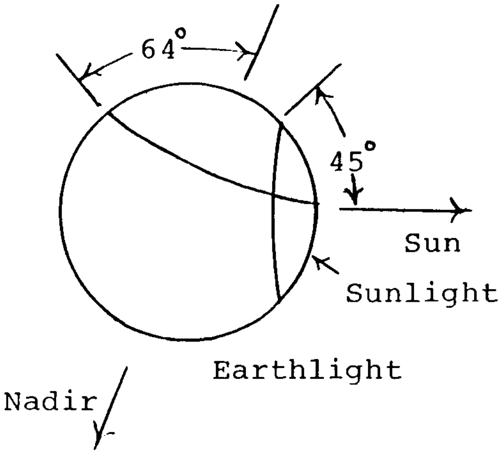

Fig. 4. Satellite lighting conditions.

Whether a sensor can simultaneously receive earth and sun light depends on the position of the satellite in its orbit. A tyical situation is shown in Fig. 4. Of particular importance is the fact that there is only a small region of satellite positions with respect to the earth and sun in which it is impossible for any sensor to simultaneously receive earth and sun light. This is shown in Fig. 5.

5. <u>Dynamics.</u> From experience it has been found that the rotational motion of a free floating satellite tends to slow over time. This is explained by the absorption of kinetic energy in the motion of internal components, such as vibration of wires, antennas, etc. Further, the motion tends toward a pure rotation about the principal axis with the largest moment of inertia [2].

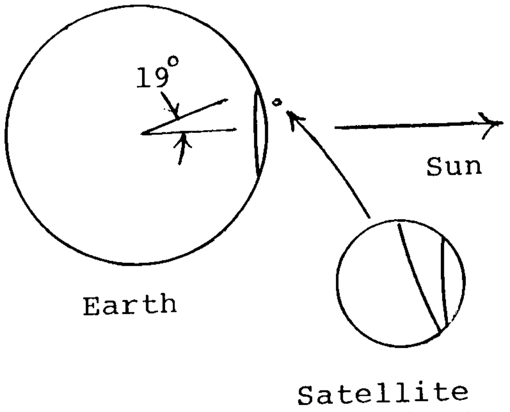

Fig. 5. Positions in which no sensor can simultaneously receive earth and sunlight.

The moments of inertia of NUSAT 1 were computed after launch using incomplete data, but taking into account the most massive components. They were $I_x = 94.3$, $I_y = 94.2$ and $I_z = 83$. Therefore any rotational motion should tend toward a pure rotation about a direction somewhere in the xy plane.

Initially the satellite had an earth orientation, rotating once per orbit. After one year, the attitude should be almost fixed inertially. It might be slightly drifting and slightly rotating about an axis in the xy plane.

6. <u>Attitude Determination.</u> To form a database, sensor readings were recorded at regular time intervals for an entire orbit. This was done every few weeks starting in January 1986. It was also performed on four different days during the third week of

June 1986.

An examination of all the data reveals several facts. Some features are coupled to the orbit but remain generally the same over the six month period. There is usually one sensor (#3 in Fig. 2) whose readings are slowly varying and remain below a certain level during the period of sun exposure. This indicates that the satellite has very little rotational motion and that the anomalous sensor is facing the sun. In addition to the short duration spikes which may be due to noise or a corrupted bit of data downlink, there are short periods from 2 to 10 minutes during which a sensor is receiving a lot of radiation (voltage down by 50% to 70%). Some of these periods occur just before entering and/or just after exiting the earth's shadow. The only feasible explanation for these is the sighting of bright spots on the earth, possible clouds and/or the sun reflection areas mentioned in Section 2.

Assuming the satellite is rotating, drifting at a very slow rate, less than one revolution per week, we can obtain a general idea of the attitude from the data of Fig. 2. For this data using a starting time of 0, the satellite had the following orbital positions:

Time	Position
19 min	Top of the orbit
42 min	Terminator
48 min	Earth shadow entrance
80 min	Earth shadow exit
86 min	Terminator
90 min	Orbit completion

By the top of the orbit we mean the position where the angle between nadir and the sun is the greatest, 141° for this orbit. Sensor #3 is generally towards the sun, receiving very little earth light after the top of the orbit, and receiving a good deal of earth light before entering and after exiting the earth's shadow. Sensor #25 must be facing back towards the terminator as the satellite passes into night. Sensors 7, 9, 19, 21, and 23 all seem to be receiving some earth light as the satellite crosses the sunlit earth. Sensors 7, 9, 23, and 25 are generally toward the earth at the first terminator crossing. With this information and a scale model of the satellite one can get an idea of the attitude by positioning the model to account for the readings at various times during the orbit.

7. Conclusion. Our method gives a rough idea of the attitude, i.e., which side of the satellite is facing the earth; this is sufficient for present operations. It might be possible to construct a computer algorithm for attitude determination using statistical method, e.g., the q method [2], but results more accurate than ±20° seem unlikely. Others [private communications] have tried to get more accurate results from similar wide angle sensors with little success.

References

1. R. Lyle, J. Leach, and L. Shubin, Earth albedo and emitted radiation, NASA SP-8067, July 1971.

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3. P. Talaga, NUSAT 1 Methods for Radar Field Strength Measurement, These proceedings.