

PRELIMINARY HARDWARE DESIGN OF ATTITUDE CONTROL SUBSYSTEM OF LEONIDAS SPACECRAFT

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ABSTRACT

In order to monitor and control the Low-Earth Orbit Nanosatellite Integrated Defense Autonomous System (LEONIDAS) spacecraft, a properly designed Attitude Control Subsystem (ACS) is necessary. The main function of the ACS of the LEONIDAS spacecraft is to track a designated target with the primary camera of the spacecraft. To control the satellite, two groups of hardware are needed: sensors, and actuators. The possible sensors hardware consists of sun sensors, star-tracker, and gyroscope; while the actuators consist of the reaction wheels and magnet torquers. There are two main objectives for this project: 1. Identify and evaluate all the possible hardware components for the ACS; 2. obtain the optimal placement of the actuators to maximize the ACS performance.

SELECTION PROCESS OF HARDWARE COMPONENTS FOR THE ATTITUDE CONTROL SYSTEM

At the beginning of the project, my first task was to obtain a cost estimate and specifications for the different hardware of the Altitude Control System (ACS). The ACS hardware can be divided into two main groups: sensors and actuators. The sensors are used to acquire the ambient conditions and orientation of the satellite. Once these parameters are obtained, they can be processed by the control software which in turns controls the actuators to maneuver the satellite based on the given information. To minimize the cost of the ACS hardware, I have contacted several different companies that specialize in spacecraft hardware equipment such as Terma, Sun Space, Vectronic-Aerospace, and AeroAstro. The key factors that we have used to make our decision on the hardware from these companies included: size/mass, power consumption, and cost. Our objective in this selection process was to ensure that the hardware that was chosen will suffice the mission requirement while maintaining the budget constraint. Pictures and specification of the possible hardware components of the ACS is shown below in Figures 1 to 6.

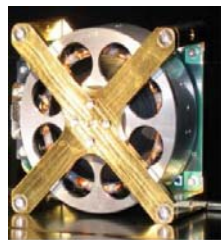


Figure 1 (left): Reaction wheel from Vectronic-Aerospace with a nominal torque of 20 milli-Nm. It has a power consumption of 25 W, mass of 1.8 kg, and an outside dimension of 115x115x86 mm. The maximum angular momentum is 1.1 Nms at a rotational speed of 5000 rpm.

Figure 2 (middle): Reaction wheel from Sinclair Interplanetary with a nominal torque of 3 milli-Nm. It has a power consumption of 2 W, mass of 225 g, and an outside dimension of 75x65x38 mm. The maximum angular momentum is 60 milli-Nms at a rotational speed of 6500 rpm.

Figure 3 (right): Magnet torquer from Vectronic-Aerospace with a nominal torque of 2.6 milli-Nm. It has a power consumption of 6 W in current mode, mass of 0.75 kg, and an outside dimension of 282x43x51 mm.

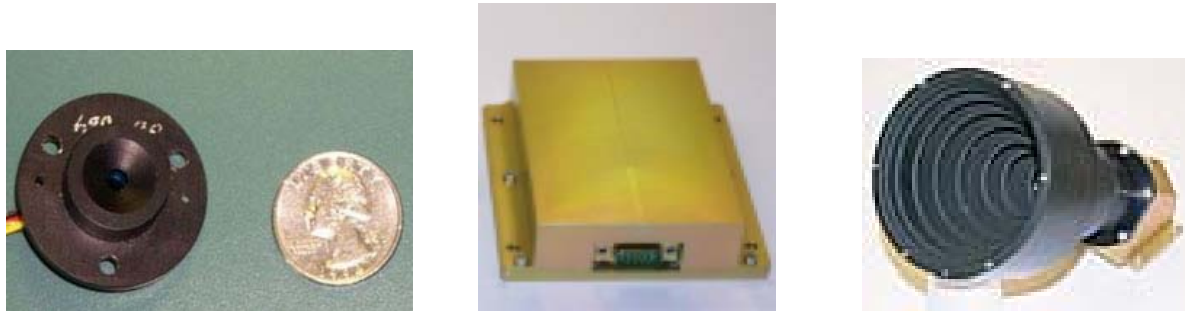


Figure 4 (left): Sun sensor from AeroAstro with a mass of 0.04 kg and an outside dimension of 34.9x24.3 mm. It has an angular accuracy of $\pm 1^\circ$. The manufacturer's recommended operational temperature range is -40°C to 93°C .

Figure 5 (middle): Gyroscope from Sun Space with a power consumption of 2 W, mass of 439 g, and a dimension of 99x117x31 mm.

Figure 6 (right): Star-tracker from Sun Space with a power consumption of 3.5 W, mass of 3.36 kg, and a dimension of 136x136x280 mm.

POSSIBLE HARDWARE CONFIGURATION

Once the ACS hardware components are chosen, my next task in this project is to obtain the optimal hardware placement to maximize the system performance. Since the sensor placement is based on the sensors field of views, there is little design involved. Therefore, the major focus on the attitude control system hardware placement is in the location of actuators, which will affect the performance of the system significantly. There are two different possible configurations for the LEONIDAS spacecraft: a 20 kg satellite and a 50 kg satellite. Each of these two configurations will require different actuators setup and therefore must be analyzed separately.

20 KG SATELLITE CONFIGURATION ANALYSES

In the 20 kg configuration, three magnet torquers from Vectronic-Aerospace are used to control the satellite. Each of the magnet torquers is able to produce a nominal torque of 2.6 milli-Nm. We know that the control torque “U”, can be express as the product of a matrix A and τ as shown below:

$$U = A\tau$$

where matrix A is a 3x3 matrix with each column representing the location of the three magnet torquers as a unit vector; and τ is a 3x1 vector with each of its entry representing the input torque of the magnet torquers.

My design goal for this part of the project is to obtain the optimal choice of matrix A such that the input torque τ can be minimized. Using MATLAB built in random number generator, I wrote a program which randomly generates a 3x3 matrix A. Using matrix A, the associated input torque τ and its magnitude can be calculated. The same process is repeated from many iterations, and whenever a smaller input torque is calculated, the associated matrix A is saved. After 10^9 iteration, matrix A has shown a convergence to the following 3x3 matrix:

$$A = \begin{bmatrix} 0.271772879206960 & -0.091481708680244 & 0.177049165975771 \\ -0.961738703351600 & 0.990139448165286 & -0.984034779367788 \\ -0.034614572121315 & -0.106089444168047 & 0.018142376411964 \end{bmatrix}$$

Once the optimal location of the magnet torquers is obtained, the maximum angular acceleration is also calculated. Since each magnetic torque is able to produce a positive and a negative torque, there are eight possible input torque values from three of the magnet torquers as shown below:

$$\tau = [\pm 2.6; \pm 2.6; \pm 2.6] \text{ milli-Nm}$$

Using all the combination of these input torques; the maximum angular acceleration about maximum principal axis achieved by the satellite is calculated to be $0.53^0 / s^2$

50 KG SATELLITE CONFIGURATION ANALYSES

In the 50 kg configuration, the actuators of the ACS consist of three reaction wheels and three magnet torquers. Two of the reaction wheels will come from Vectronic-Aerospace with a nominal torque of 20 milli-Nm and the last one will come from Sinclair Interplanetary which has a torque of 3 milli-Nm. In this design, the reaction wheels will be used to maneuver the satellite. The two more powerful reaction wheels from Vectronic-Aerospace will be placed at the

principle x and y axis. The smaller 3 milli-Nm reaction wheel from Sinclair will be placed at the z axis (the gravitational direction in orbit) since smaller magnitude of torque is required in that direction. Although, the reaction wheels are usually more powerful actuators in the ACS, they will run into problems of torque saturation limit. Thus, in order to avoid this problem, the magnet torquers can be used to de-saturate the reaction wheels. In this part of my analysis, the goal was to obtain the optimal placement of the magnet torquers such that we can optimally counter and de-saturate the reaction wheels torques. Similar to the magnet torquers, the reaction wheels are able to produce a positive and a negative torque. Therefore, there are again eight different combinations of input torques from the reaction wheels as shown below:

$$\tau = [\pm 20; \pm 20; \pm 3] \text{ milli-Nm}$$

Using a similar approach as in the 20 kg configuration, MATLAB random number generator was used to obtain the optimal location of the magnet torquers. After 5×10^8 iterations, matrix A converged to the following matrix for all 8 possible input torque vectors. The optimal axial placement of the magnet torquers are given by the vectors of the following matrix:

$$A = \begin{bmatrix} -0.9999900715767395 & 0.727926615027645 & -0.052419320657515 \\ 0.009933654715342 & 0.683692702607929 & -0.996486848699102 \\ -0.009994053824494 & 0.051837549470058 & 0.065315964293108 \end{bmatrix}$$

CONCLUSION

The attitude control subsystem allows the LEONIDAS spacecraft to precisely and rapidly track the designated target with the primary camera of the spacecraft. There are two design configurations based on the possible mass of the satellite: 20 kg and 50 kg. In the 20 kg configuration, three magnet torquers are used to actuate the satellite yielding a maximum angular acceleration of $0.53^0/s^2$. In the 50 kg configuration, three reaction wheels and three magnet torquers are used to control the satellite. The three magnet torquers will be used to de-saturate the reaction wheels, thus maximizing the torque output and angular acceleration of the system. The MATLAB computational software with a trial and error method is used to obtain the optimal location of each of the magnet torquers. With the optimal placement of the magnet torquers in both designs, the attitude control subsystem performance of the spacecraft can be maximized.

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REFERENCES

Bayard, D (2000). An Optimization Approach to Orienting Three Spacecraft Reaction Wheel Actuator with Application to the Europa Orbiter. Jet Propulsion Laboratory, CA September 2000.

Sauer, T. (2005). Numerical Analysis. Addison Wesley (December 17, 2005).