ACTIVE ATTITUDE CONTROL OF A CUBESAT USING PERMANENT MAGNETS.

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Introduction: CubeSats are nanosatellites that can be sent up in low earth orbit with previously scheduled missions. The small size, a 10 cm cube, and low cost of these CubeSats allow for programs to test new technology and designs on a small scale before committing to a large scale mission. Attitude control is the method of orienting a satellite in space. Current procedures include using passive attitude control which is fixing a permanent magnet to the CubeSat to maintain alignment with the earth's magnetic field, such as the RAX CubeSats [1], or to use electromagnetic torquers to move the CubeSats.

Objective: The goal of the project was to examine the applicability of permanent magnets for active attitude control in CubeSats. For this project, we rotated permanent magnets to orient the CubeSat. The magnet is rotated an initial angle away from its equilibrium position where it is aligned with the Earth's magnetic field. Then the magnet feels a torque created by the Earth's magnetic field, and the satellite will be rotated back to its equilibrium position. To test this concept, the team examined the effects of a magnet's rotation in a constant magnetic field on the motion of a small craft.

Method: Because the torque felt by the magnet due to the earth's magnetic field is minute we created a puck to float our instrumental components on water to minimize friction. On this puck was a Beaglebone Black, a battery source that provides 5V, a wireless antenna, a motor, a magnet, and two geometric patterns as shown in Figure 1.

Figure 1: Our puck with the instrumental components floating in a tub of water

The Beaglebone Black controlled a motor attached to the magnet. Code was written in Python to turn the magnet a specified number of degrees which would then reorient the puck so that the magnet aligned with the Earth's magnetic field, similar to how a compass needle will always rotate back to north. The current method for determining how far the magnet has been rotated is to track one of the geometric patterns attached to the magnet. A LabVIEW program was written to use live video to track the motion of the geometric patterns, recording time, position, and angle of rotation of the puck. The code then sends the angle of rotation over a UDP network. This information is used by the Python program. The observed oscillations of the puck were compared to the predicted results to prove active attitude control could be applicable.

Theory: A dipole in a constant magnetic field when rotated an angle away from its equilibrium position oscillates in the same manner as a simple pendulum. Without any retarding or frictional force, the magnet will oscillate indefinitely about the equilibrium position. Most introductory physics courses simplify the topic of simple harmonic oscillators to a linear differential equation using the small angle approximation. For large angles though, the motion of a pendulum is described by a nonlinear differential equation that must be approximated or numerically integrated with a computer. Using the constants for a dipole in a constant magnetic field, the equation for the period of a free, undamped, simple pendulum for large amplitudes is

$$\mathrm{T}=\frac{2}{\pi}\mathrm{K(k)T_0} \qquad (1)$$

where $\mathrm{k}=\sin\left(\frac{\theta_0}{2}\right)$, θ_0 is the initial angle of displacement, $\mathrm{K(k)}$ is the complete elliptic integral of the first kind, $\mathrm{T_0}=2\pi\sqrt{\frac{\mathrm{I}}{\mathrm{mB_e}}}$ with I being the moment of inertia of our system, m is the magnetic moment of our magnet, and B_e is the magnetic field of the earth. Over the years, many scientists have developed formulas to approximate the period of oscillations for a simple pendulum for large amplitudes. The most accurate approximation so far was derived by Lima and Arun [2], where the period of an undamped pendulum is

$$\mathrm{T_{LA}}=-\mathrm{T_0}\frac{\ln\left(\cos\frac{\theta_0}{2}\right)}{1-\cos\frac{\theta_0}{2}} \qquad (2)$$

Thus for an ideal case without friction, we expect values of the period of oscillations for our dipole to be the values listed in Table 1.

θ_0 [deg]	T_{LA} $[sec]$
0	0

15	76.39
30	77.39
45	79.11
60	81.66
75	85.20
90	90.00

Table 1: Values of the period for a given initial angle of displacement using the Lima and Arun approximation.

In order to determine the equation of motion of a dipole in a constant magnetic field, we must calculate the torque of our system.

$$\tau = I\alpha = m \times B_e \quad (3)$$

$$I\frac{d^2\theta}{dt^2} = mB_e \sin\theta \quad (4)$$

If we include a damping term due to the frictional forces of our puck floating on the surface of water, then our equation of motion becomes

$$I\frac{d^2\theta}{dt^2} = mB_e \sin\theta + \frac{\pi\mu r^4}{2h}\left(\frac{d\theta}{dt}\right) \quad (5)$$

where μ is the dynamic viscosity of the fluid (water), r is the radius of our floating puck, and h is the depth of the fluid. We numerically integrated equation 5 using a Verlet integration scheme in order to determine at what time our system will be at a specific angle, as seen in Figure 2.

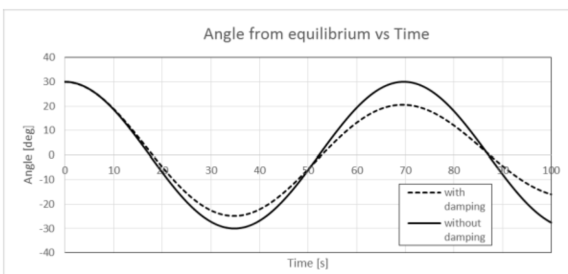

Figure 2: Numerical integration of the angle from the equilibrium position vs time for our puck with and without damping for an initial angle of 30°.

Results and Discussion: In our first test, the puck with a stationary magnet affixed was manually turned to 30° then released. The magnet caused it to rotate back in to alignment with Earth's magnetic field after a few oscillations, as seen in Figure 3. In this test, we see that the period is about 170 seconds.

In the second test, the puck started at 0°, the motor and magnet were turned to 30°, then the puck was allowed to rotate until the magnet was again in alignment with Earth's magnetic field. In Figure 4, we see that the period of oscillation lasted about 166s.

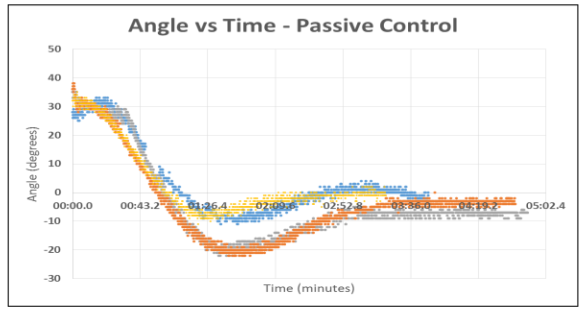

Figure 3: Each color represents a different trial for testing passive attitude control.

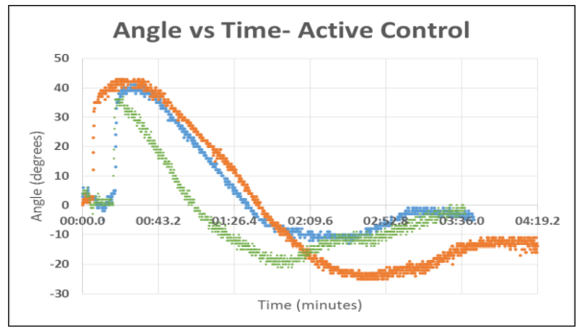

Figure 4: Each color represents a different trial for testing active attitude control.

Figures 3 and 4 show that passive and active attitude control systems using a permanent magnet provide similar periods of oscillation, indicating that active attitude control is a viable option for adjusting the orientation of a CubeSat.

The experimental periods were about 100 seconds longer than the one predicted by the theory. This is likely due to drag factors not considered in the theoretical equations such as surface tension, air flow in the room or unbalanced weight distribution on the puck.

Future Work: The next step is to add additional magnets to the system. Currently the rotation can only be controlled along one axis, but 3-dimensional attitude control will be necessary while the CubeSat is in orbit. With additional magnets, the camera system used to track the angle of rotation will not be adequate, and a magnetic encoder will need to be incorporated to provide this information for each magnet. In orbit, no natural damping of the oscillation will be provided by the environment, therefore controlling functions will need to be implemented.

References: [1] J. C. Springmann et al. (2012) Acta Astronautica, 75, 120-135. [2] F.M.S. Lima and P.Arun (2006) Am. J. Phys., 74, 892-895

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