

**PERMANENT MAGNET ACTIVE ATTITUDE CONTROL OF A CUBESAT FOR SPACE INSTRUMENTS.**

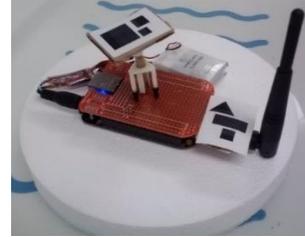
J. Lloyd<sup>1,5</sup>, S. Matlock<sup>2,5</sup>, M. Nieberding<sup>3,5</sup>, and P.A. Huang<sup>4</sup>, <sup>1</sup>Arkansas Tech University, Department of Mechanical Engineering, [jilloyd714@yahoo.com](mailto:jilloyd714@yahoo.com). <sup>2</sup>Purdue University, Department of Aeronautics and Astronautics, [smatlock@purdue.edu](mailto:smatlock@purdue.edu). <sup>3</sup>University of Arizona, Department of Astronomy, [mnieberding@email.arizona.edu](mailto:mnieberding@email.arizona.edu). <sup>4</sup>University of Arkansas, Department of Mechanical Engineering [phuang@uark.edu](mailto:phuang@uark.edu). <sup>5</sup>Arkansas Center for Space and Planetary Sciences, University of Arkansas

**Introduction:** CubeSats are nanosatellites (low cost 1-10kg sats) which allow for testing new technology and designs on a small scale before committing to a large scale mission. Furthermore, recent developments call for interplanetary CubeSats to explore near and deep space destinations of interests. The work reported here is on a novel active attitude control system that requires low power while providing high control response when operating near bodies with a magnetic field, possessed by most of the planets in our solar system. The intended application is for a new CubeSat-based space instrument, such as a space telescope or remote sensing instruments. Current procedures include using permanent magnets as passive attitude control, such as the RAX CubeSats [1], or to use electromagnetic torquers. Other methods such as momentum wheels require dumping of excess momentum accumulated thus is not a self-contained attitude control system.

**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. 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.



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

**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 non-linear 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

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

where  $k = \sin\left(\frac{\theta_0}{2}\right)$ ,  $\theta_0$  is the initial angle of displacement,  $K(k)$  is the complete elliptic integral of the first kind,  $T_0 = 2\pi \sqrt{\frac{I}{mB_e}}$  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

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

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

$\theta_0$ [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.

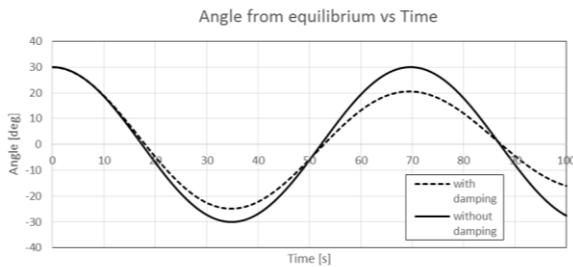
$$\tau = I\alpha = m \times B_e \quad (3)$$

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

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

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

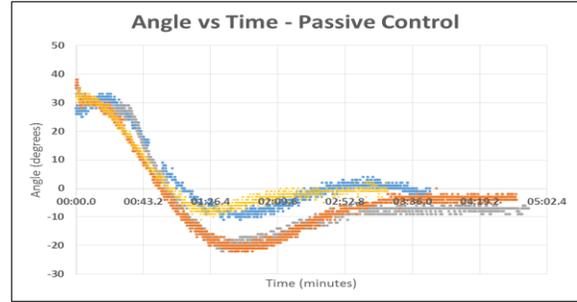
where  $\mu$  is the dynamic viscosity of the fluid (water),  $r$  is the radius of our floating puck, and  $h$  is the depth of the fluid. We numerically integrated equation 5 using a Verlet integration scheme in order to determine at what time our system will be at a specific angle, as seen in Figure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



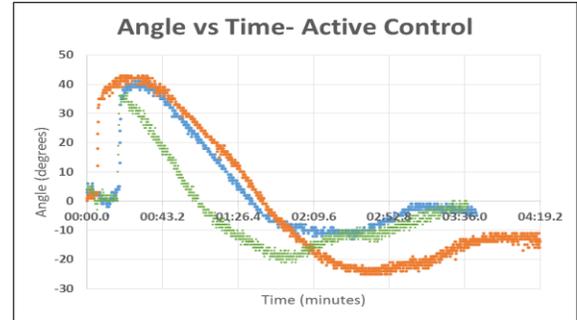
**Figure 2:** Numerical integration of the angle from the equilibrium position vs time for our puck with and without damping for an initial angle of 30°.

**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. 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.



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



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

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

**Acknowledgments:** Special thanks to Derek Meyers, Ryan Moore, and Armando Villegas for all your help. This work is part of the NSF Research Experiences for Undergraduates Grant AST-1157002 at the University of Arkansas Center for Space & Planetary Sciences.