Satellite Control Using the Earth’s Magnetic Field

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Introduction:

With modern spaceflight on the verge of commercialization, cheap and effective control systems are a focus of research. Previous and current methods of spacecraft control include adding thrusters, using a gravity boom, using a rotating momentum wheel, and using magnetic torque coils.

A control system must be designed based on the needs of each individual mission. The control system I choose was designed to control a low Earth orbit (LEO), small scale satellite (<50kg), built to study reflected GPS signals (some pointing requirements). Based on mission goals; my research focused on using the interactions between magnetic torque coils and the Earth’s magnetic field.

Method:

For a complete mission timeline there are a series of control modes. The first mode of control is “de-tumble”. This stage is implemented after the satellite is released from the launch vehicle. The onboard sensors will send the rate of spin to the designed control logic, thus ceasing any rotation. The second mode of control is “gross correction”. After rotation has stopped another set of sensors will detect the angular offset from a reference frame with the antenna pointing towards the Earth. The control law will then read this offset and move to adjust the satellites pointing direction. Modes one and two will be controlled using Proportional Integral Derivative (PID) control.

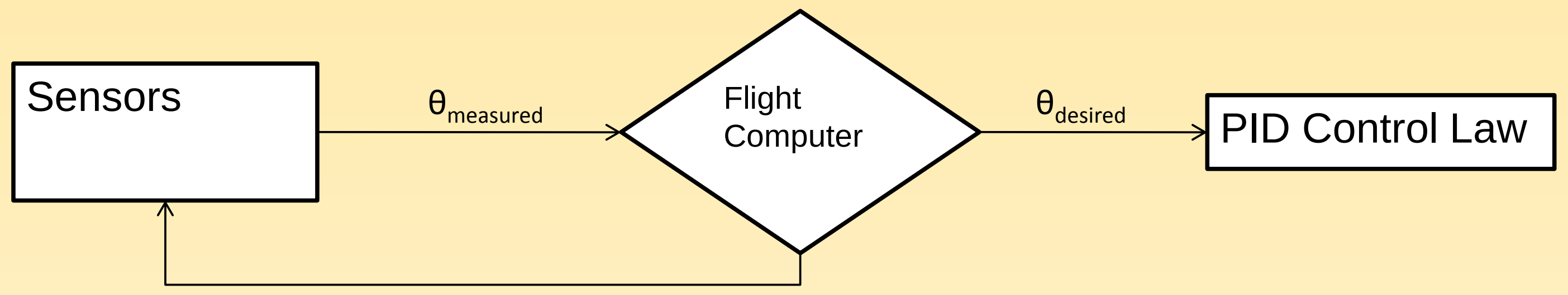

Figure 1: A block model of the PID controller action. First the sensors check the angular measurement, next the flight computer decides if we are offset from the desired angle, and finally the PID control law adjusts the angle.

The final mode of control is “minor correction”. Once the spacecraft is pointing the desired direction, things such as aerodynamic drag, solar pressure, or J2 effects will potentially disturb the satellite. For this mode a bang-bang controller was built. The bang-bang control is an energy efficient method to control the satellite in this stage. The sensors periodically measure the angular rotation rate, and send the data to the flight computer. If this data is within a certain lower and upper bound the controller does nothing, if it is outside of there bounds due to disturbances, the controller activates to bring the satellite back into the bounds.

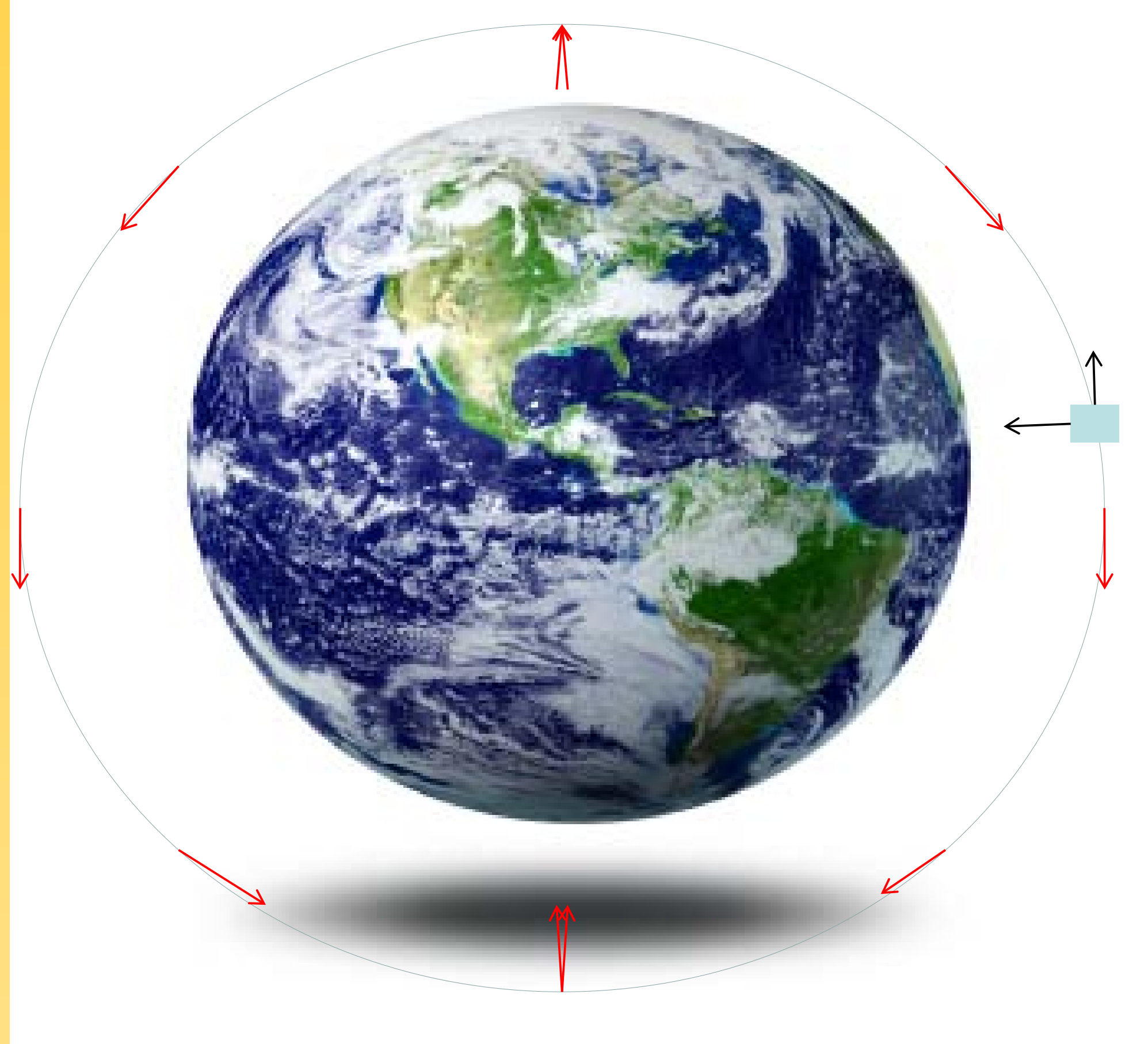

Figure 2: Schematic of the satellite as it moves around the Earth. Red arrows represent magnetic field directions. Black arrows are the body frame of the satellite.

All three modes of control are designed using strictly torque coils. These torque coils are copper coils wrapped around ~150 times and placed on all faces of the satellite. When a current is driven through the coils, a magnetic field is formed normal to the coil face. This magnetic field will want to align, or oppose itself with the Earth’s magnetic field depending on the direction of current. Using all three faces gives control authority about all three satellite body axis's.

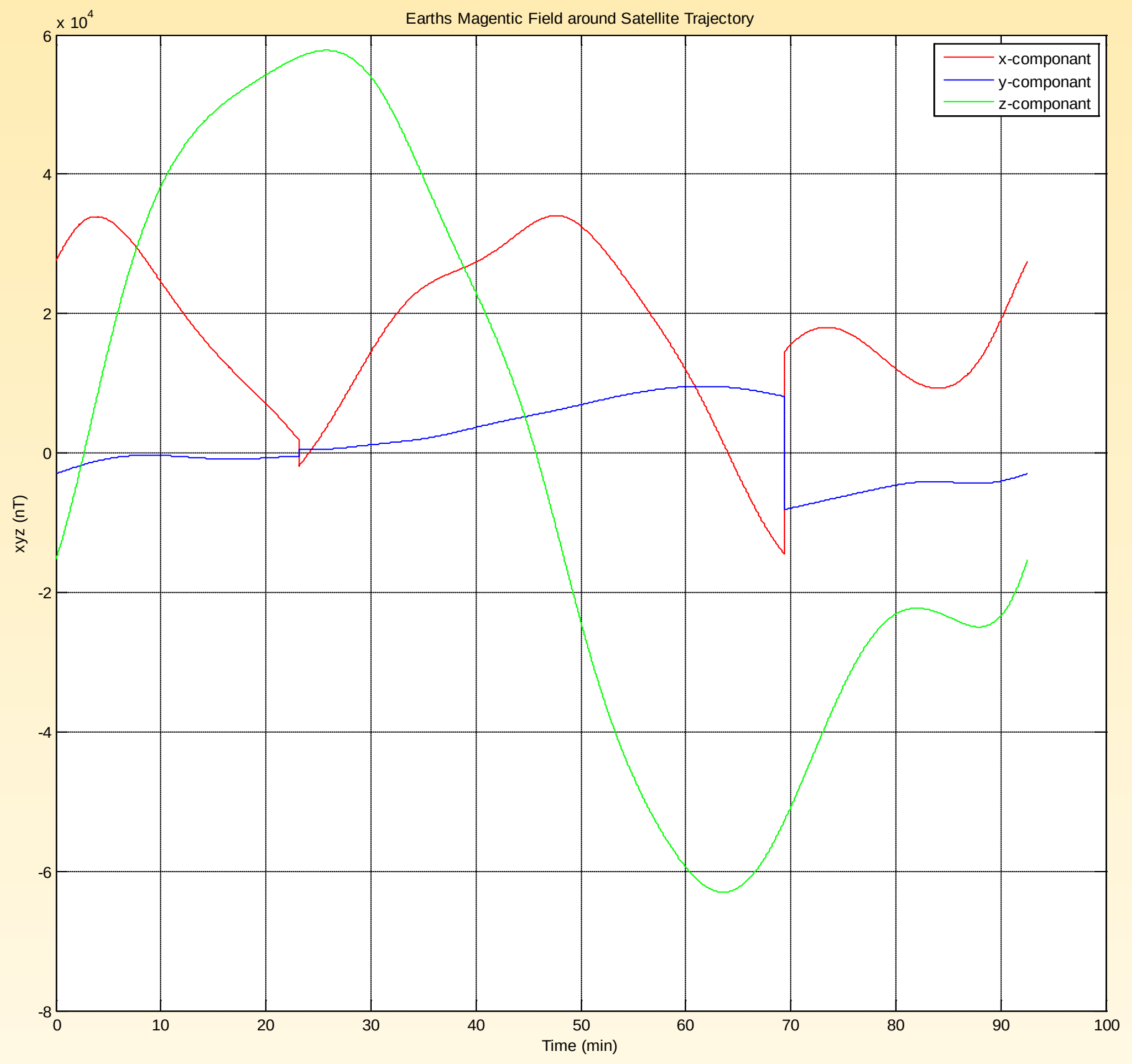

Figure 3: The magnetic field of the Earth was modeled and analyzed in MATLAB. This particular chart shows the values of the Earth’s magnetic field in the north-east-down reference frame of a satellite in a polar orbit.

Results:

Disturbance torques are on the order of 10^{-5} – 10^{-6} Nm depending on altitude. In lower LEO (~300km) aerodynamic drag is the dominating disturbance, in higher LEO (~1000km) solar torque become more of a relevant disturbance.

Magnetic coil control toques are on the order of 10^{-4} - 10^{-5}, depending on orbital inclination and desired axis of rotation. As orbital inclination moves from 0-90 degrees control authority swaps dominant axis. For example at an inclination of 0^0 it is much easier to rotate the satellite about its axis pointing in the direction of motion. However, for a satellite in polar orbit it is much easier to rotate about its axis orthogonal to the direction of motion and to the Earth pointing direction.

Conclusion:

In conclusion although all 3 modes of control were not entirely developed in the allotted time frame. I can safely conclude that it is feasible to built a cheap and effective control system using only torque coil interactions with the Earth’s magnetic field.

Additionally I can conclude that during mode 3 my design will be able to counteract all disturbance torques using very little energy. Also during mode 3 it would be ideal to have a polar orbit; thus allowing for maximum control about the primary rotation axis.

Some possible sources of error include inaccuracy or bugs in MATLAB coding that should be further reviewed and updated. Also inconsistencies in densities at varying LEO altitudes. Future work includes final touches on bang-bang control and software to hardware conversion. Also advancing preliminary models of the PID control designed for modes 1 and 2. These advancements include further examination of control gains, and better understanding of saturation (or control limits). Control limits change with changing magnetic field; thus each different point in the orbit must be examined and analyzed.

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