Gravity and magnetism: theory versus practice onboard the ISS

Motivation

We are three students in year 6 and have not studied the earth's gravity and magnetism in detail. However, our general knowledge has indicated to us that both extend far away from the surface of the earth. During our brainstorming sessions about potential proposals for an experiment onboard the ISS, we have noticed a discrepancy; the astronauts are floating in space and are told to be in “microgravity” which should imply that the gravity is negligible there. The word “micro” caught our attention here which was used instead of “zero” which led into a discussions with our mentor and our families.

We heard during these discussions that in 1915 Albert Einstein formulated the theory of General Relativity which says that gravity is equal to acceleration. If the ISS is not accelerating, then the people who designed the ISS must be perfectly balancing the gravitational field of the Earth.

We now understand that the gravitational pull of the earth at the ISS is quite high (~88% percent of that on the earth) and it is near zero (hence “micro”) due to ISS' own motion [1-4]. We have been shown that gravitational pull on the surface of the earth could be estimated using the accelerometers on common mobile phones and tablets and visualized using “Arduino Science Journal”. So this is the starting point for our experiment for the AstroPi onboard the ISS.

During our discussion, we have become interested in also charting the magnetic field of the earth. Furthermore, since the ISS had to be constantly “free-falling” with the exact velocity, it had to be “boosted” regularly. We have decided to see if, by coincidence, a boost occurred during our data acquisition and, if so, notice when the rockets are boosted.

We want to learn important lessons on gravity, magnetic fields, how a satellite works, scientific method and carry out an experiment testing whether the theory and real-life approximate each other well or not within the limitations of our tools. We understand that we are both studying life on the ISS (gravity) but also “Life on Earth” (how its gravity and magnetism changes with position on Earth). We have picked “Life on Earth” since we need to photograph the Earth as you will see below.

Hypotheses

H1: The sensors on AstroPi - inertial measurement unit, in particular accelerometer, gyroscope - can be utilized to separate different directions of acceleration and identify the strength of the earth's gravitational pull on the ISS.
H2: The distance from the earth's core is the main determinant for the strength of gravity which we have calculated to be 8.7 cm^2/sec. It will not depend on the path of the ISS since the height of the ISS is approximately constant throughout.
H3: Similar considerations are true for the magnetic field except that if we end up recording over the South Atlantic anomaly, we will see a strong change in the magnetic field.

Discussion, risks and risk mitigation

There are some issues that we will be ironing out as we write the script, simulate it on the earth and finalize the script for running on the AstroPi. We call these risks and we now discuss how we will mitigate them.

One potential issue is that we have not yet understood whether the vector sum of the acceleration will be near-zero or if all axes will read zero. We have simulated this by dropping a mobile phone while running "Arduino Science Journal" and recording acceleration. The acceleration on all three axes was near zero. Our risk mitigation strategy is to rely on physics [1-4] to solve this problem. By knowing the angular motion of the ISS from the IMU unit and calculating its velocity from the camera images (e.g. as done by Ref [9]), we can figure out the amount of gravitational pull that the ISS had to overcome at this altitude by selecting this particular velocity and if it is consistent with Newtonian physics [10].

Another potential risk is that the amount of data and the concepts could overwhelm our limited experience in programming, data analysis and interpretation. Our mentor is a physics professor with a lot of experience in instrumentation, experimental procedures and data analysis. We are enthusiastic and motivated to work with him to overcome this risk.

References

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Methods

Data logging and representation

Our main goal is to log data about the position of the ISS [6] and the data from the IMU sensors [7] at regular intervals. Our current plan is average data from one second of measurements and log the mean/median and the standard deviation. This will give us measurements of three axes of acceleration (x,y,z of unknown orientation relative to AstroPi placement), six axis of movement (yaw, pitch, roll, x, y, z relative to AstroPi placement) and three axes of the magnetic field (x, y, z relative to AstroPi placement) strength. In addition to this, we will log a timestamp from the real-time clock. We will experiment with the simulator and the physical AstroPi before preparing the final program in order to fine-tune this information.

There is no on-board sensor to locate the ISS precisely over the earth. Instead, we will use the method described in Ref. [6]. In order to relate these findings to the structures over the earth, for example, a tall mountain may affect the gravitational [11] or magnetic fields, we will also record visible light images from the camera at regular intervals. As described in the risk mitigation procedures, we will also use the images to determine the velocity of the ISS. In order not to be overwhelmed with the amount of information, we will record at about one image/per second. We will replace night-time images which may be dark with estimated images from satellite imagery, e.g. Google Earth, based on position approximation. This will also be fine-tuned before submission.

The data will be logged in csv files [8] and our calculations show that we will be way below the 3Gb limit. One important consideration is to define the resolution for the HQ Camera module so as not to pass this limit. We will use previous data-sets, e.g. Ref. [8], to practice how to analyze and represent the data. Of particular interest will be the evolution of independent axes and vector sums of these parameters over time, representation of them over positions over the earth and either automatic or manual detection of special events, e.g. if a boost [4] occurs.

We plan to utilize Python and associated libraries that are allowed for use on the AstroPi for both the script that will run on the AstroPi and also for analyzing the calculated data.