ANALYSIS OF INERTIAL MEASUREMENT DATA FROM A MODEL ROCKET PAYLOAD

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Abstract

As part of a student-educational experience in telemetry, beginning undergraduates build, program, and test small payloads flown in model rockets. These payloads, nicknamed ‘femtosats,’ collect and transmit real time telemetry on the rocket’s performance. The femtosats measure the inertial motions of the model rocket, providing info to extract the flight path. The individually student-designed femtosat circuit board includes a simple inertial measurement sensor that collects acceleration data in the form of *x, y, z* acceleration vectors which are transmitted in real-time to a radio ground station. The focus of this paper is the collection and analysis of the data from the telemetered inertial measurement sensor and how it can be interpreted and applied in simple model rocket motion analysis.

Introduction

A student-led group at Brigham Young University (BYU) has been making small printed circuit boards (PCB) as model rocket payloads that are designed to collect and transmit acceleration telemetry. The sensor boards are colloquially referred to as ‘femtosats’ by the participants since they are inspired by KickSat [1]. The goal in building these femtosats is to help students learn to design, build, and program real-time sensor systems that include radio telemetry communication. This project helps prepare students for more advanced research in larger, more complex systems as well as identify the most promising undergraduate students.

After successfully designing, building, and testing their sensors, the student teams launch their femtosats in small model rockets to gather data which is received by a software-controlled radio and recorded on a laptop. The resulting data can be analyzed to evaluate the rocket performance and help students improve the design of their systems.

In this paper we briefly describe the femtosat design concept (implementation of individual femtosats may vary), discuss data collection and analysis, and possible future work.

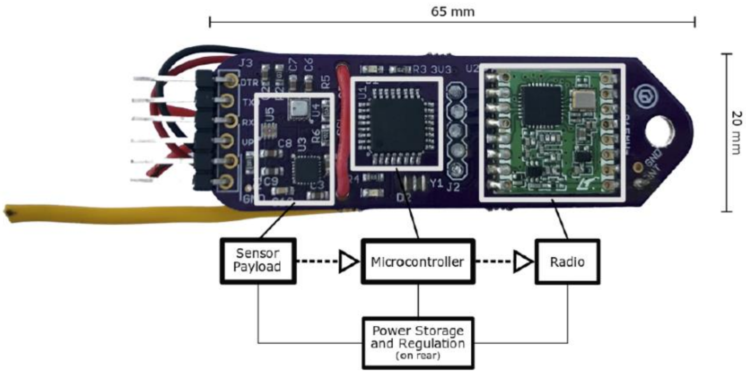

Fig. 1: Hardware photograph of a typical femtosat showing the key components. Power comes from a backside-mounted battery. The yellow wire at left is the antenna.

BYU Femtosats

The BYU femtosats are typically implemented on 20 x 65 mm PCBs, see Fig. 1. To simplify the design, all students use an ATmega328 microcontroller as the main processor. The processor interfaces with a PMU-9250 inertial measurement unit (IMU) and the RFM69HCW software radio chip which transmits real time telemetry as character arrays in the 915 MHz ISM band. The detailed design of the femtosats and the telemetry are described in [2]. The example femtosat in this paper includes sensors for measuring 3-axis acceleration and atmospheric pressure. However, we focus only on the acceleration data collected by the femtosat during a series of flights. The model rocket is a standard Astra 3 model, 15” long, 1.18” diameter rocket used with electrically ignited standard Estes C6-5 engines. A 24” Estes rod-guided launch pad is used, and the rocket is recovered with a 18” parachute at the end of flight.

As described in [2], the ground station antenna is handheld and manually pointed at the rocket during flight by a student assigned to this task. Manually pointing the antenna has limited accuracy but keeps the ground station costs low.

Data Analysis

For an ideal model rocket launch, a simple parabolic flight is observed by the naked eye, with the rocket landing close to the original launch site; the landing site shifts in the direction of the wind. Furthermore, wind and or misalignment of the rocket fins can tilt the flight off ideal trajectory during the upward flight phase and cause rotation of the rocket during flight. While the nominal acceleration of the payload can be predicted with reasonable accuracy based on the rocket weight and the specific impulse of the engine employed, understanding the deceleration caused by the parachute ejection charge is more difficult to predict. This impulse can be calculated using the data from the femtosat though we don’t fully address it here. Further, the femtosat-measured acceleration data can (in theory) be used to predict the flight path and velocity by integrating the observed acceleration values.

Analysis of the femtosat acceleration measurements are made with this goal in mind. Note that acceleration collected prior to ignition can be used to help determine the orientation of the IMU relative to the earth.

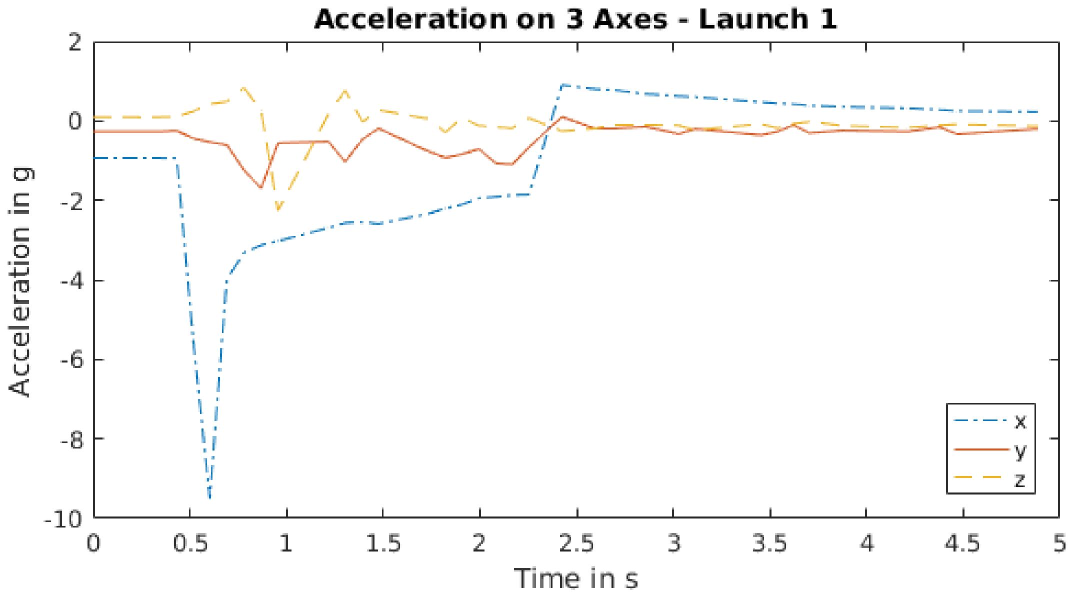

Fig. 2: Measured acceleration versus time for a particular flight. Launch occurs at approximately 0.5 s, with the engine shutting off at 2.3 s. Launch impact on the ground occurs 30 s later (off the plot).

From the data shown in Fig. 2, the calculated total force on the sensor at rest is found to be -0.92 g and is the sum from all 3 axes. This is predominantly from the x axis which is close to -1 g, and at an angle of 2.12 deg from the vertical. A small amount of this force is registered on the *y* and *z* axes because the femtosat is mounted at a slight angle relative to vertical. Once the motor is ignited, there is an initial upward thrust resulting in a force of -9.5 g. Both the y and z axes show changes after this which are from the rocket tilting and rotating after leaving the launch pad. The motor burns for about 1.9 s, with the final velocity at this point calculated to be 7.84 m/s. Once the motor is exhausted, the rocket begins to decelerate due to air friction and gravity. After this time, the rocket gradually slows down until the parachute is deployed (not shown).

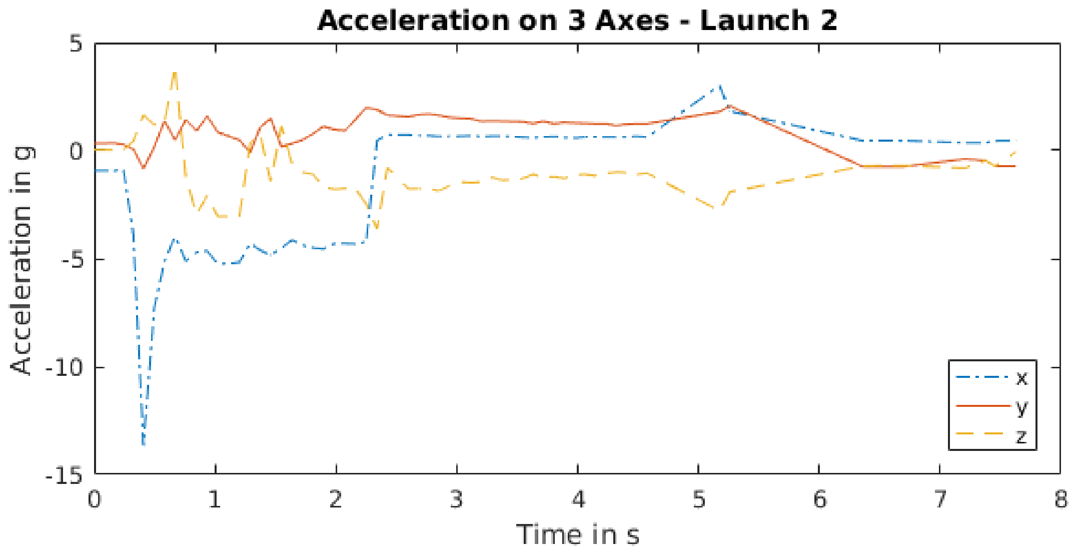

Fig. 3: Measured acceleration versus time graph of second flight. Launch occurs at 0.2 s with the engine shutting off at 2.4 s. The parachute charge is fired at 4.7 s, and takes effect at 5.3 s.

The second launch displayed in Fig. 3 is similar to the first launch shown in Fig. 2. The calculated initial force is found to be -0.93 g and is nearly aligned with the *x*-axis. The angle is 0.99 deg from vertical which is why the *y* and *z* axis accelerations are not at zero. The initial launch thrust is -13.66 g along the x axis. At 4.7 s, the parachute ejection charge goes off. All three axes show this occurring. At 5.3 s the parachute takes effect. The rocket then has uniform descent. When this point occurs, the rocket was calculated to have a horizontal displacement of 11.81 m from the launch pad at an altitude of 65.71 m high. A longer telemetry record shows the force returns to -0.93 g at ground contact.

Lessons Learned and Future Work

One of the key lessons learned during the project is the need to properly align and secure the femtosats in the rocket's payload bay. Due to the femtosats' lightweight and small size, the inexperienced students merely inserted the boards into the padded tubular payload section rather than attaching or mounting the board to the fuselage. In hindsight, this was a mistake as the board sometimes shifted in flight, which altered its orientation and measurement accuracy.

The most critical problem is that the ground station did not always receive telemetry for each launch. Out of the six launches made, only two flights were completely recorded, with a third flight recording data only after a few seconds into the flight. Some variation in motor thrust from flight to flight was noticed, which we would like to study further.

As a result of the experience, students have been working on ways to improve the system performance and have been developing new ideas for alternate implementation schemes. As noted previously, maintaining the radio telemetry link during full flight has been difficult, due in part to the directional receiver antenna employed at the ground station. For future flights, the ground station will be moved further from the launch site to reduce the pointing accuracy requirements, and equipment with higher sensitivity and a higher telemetry rate will be implemented to help maintain the ground station connection. Vibration Isolation may additionally help by minimizing high frequency noise and is being considered.

Another lesson learned is the importance of firmly securing the femtosat boards within the rocket payload bay so that they do not shift during flight. Students would also like to focus on the integrals for calculating the velocity and position of the rocket from launch until landing, which would include finding the alignment of the rotation and initial calibration of the sensor.

Conclusion

As an educational experience this project has been a great opportunity for undergraduates to build and test hardware, learn about telemetry and digital communication, and learn about data analysis. Students successfully demonstrated real-time telemetry links during flights up to 70 m and lasting up to 30 s. While only a simple single-chip IMU with limited performance was used, it proved to be adequate for meeting the necessities of helping students design sensors for a model rocket launch.

References

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