TELEMETRY SYSTEMS FOR A SOUNDING ROCKET AND ITS PARALITES

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ABSTRACT

During descent, a sounding rocket ejects a number of 1U cubesat sized objects, which descend on parachutes independently of the rocket. These ”paralites” allow for testing of different parachute designs and payload deployment methods for future missions. This paper describes a telemetry systems used for both the sounding rocket, and the ejected paralites. Commercial off the shelf components are combined with student researched and designed components to produce a system which is flexible enough to accommodate both the current needs, and future opportunities.

INTRODUCTION

This paper describes the design of a sounding rocket entered into the Spaceport America Cup competition [1], 30k SRAD division. This annual competition is hosted by the Experimental Sounding Rocket Association [2]. In 2021 the virtual competition had entries from approximately 200 college and other amateur teams from 20 countries. The 30k SRAD division requires a rocket that will hoist a 4 kg payload to 30 000 feet (30k) using a student researched and designed (SRAD) motor. During decent, the rocket will deploy a collection of 1U cubesat sized objects, which are stored in the rocket's payload bay during assent, as seen in Figure 1. These ”paralites” are used to test various parachute designs and payload deployment methods for future missions.

The sounding rocket has a commercial off the shelf (COTS) telemetry system, which has been used by the team for a number of 10k class rockets. However the system is too large and massive to be used in the deployed paralites. The system also lacks the flex ability required to allow the sounding rocket system to act as a data collection and relay station for the much smaller paralites. An SRAD telemetry system for both the sounding rocket and paralites is being developed.

The following section gives an overview of the sounding rocket mission, followed by the avionics systems used on the rocket. This is followed by sections which describe the paralites, their de-

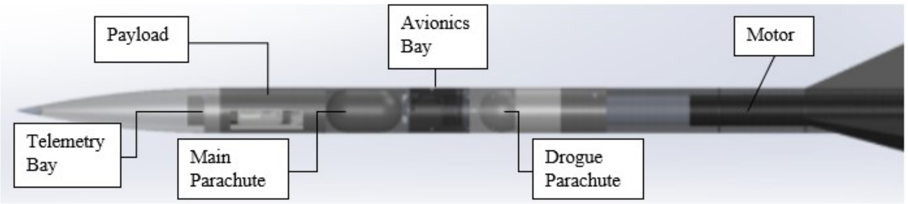

Figure 1: Sounding Rocket Design

ployment, telemetry systems, and challenges faced by the team's decision to move from fiberglass body rockets to carbon fiber based designs.

SOUNDING ROCKET MISSION OVERVIEW

The minimum requirements for mission success is for the rocket to achieve an altitude of at least 30 000 feet on a SRAD motor, and be recovered in a re-launchable state within six hours of landing. Optional tasks include telemetering rocket location and velocity during the entire flight, measuring parachute drag characteristics in-flight, and deploying paralites during descent.

The sequence of events during the mission are shown in Figure 2 and Figure 3. A drogue parachute is deployed at apogee, to allow the rocket to descend nearly vertically until it reaches 1500 feet. At that point the main parachute is deployed to slow the rocket sufficiently that it will not be damaged upon landing. At an altitude of 900 feet the paralites are ejected, and each deploys its own parachute.

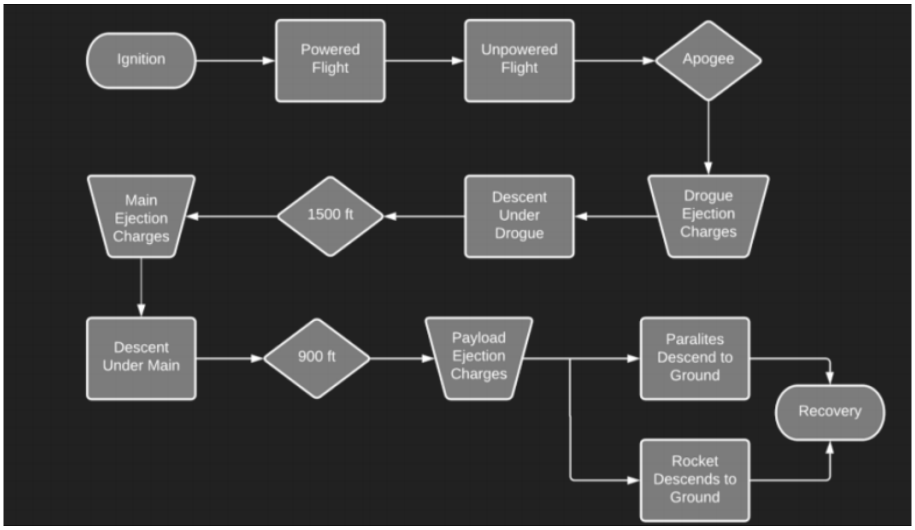

Figure 2: Mission Sequence of Events

As a result of the paralite deployment, the number of events in this recovery sequence is more than the average dual-deploy rocket. Additional work has been done to ensure each event will happen

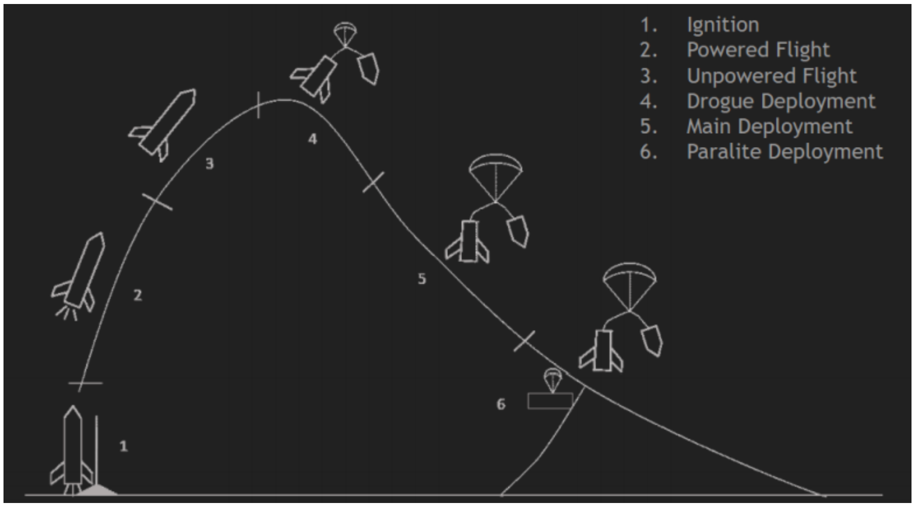

Figure 3: Mission Profile

quickly and safely, so that all components will reach the ground intact. One of the primary results in the team's extensive experience with 10k launches is the robust launch preparation checklists that have been developed for each subsystem. These lists have been through many iterations to improve the efficiency of work in addition to making sure every detail is accounted for when preparing the rocket for its launch and recovery deployment.

SOUNDING ROCKET AVIONICS

The primary telemetry and flight control computer for the rocket is a Altus Metrum Telemetrum 3.0 device [3]. It will trigger explosive charges to deploy the drogue parachute one second after it has determined the rocket has reached apogee. The apogee measurement is based on an internal altimeter. The Telemetrum will fire charges to deploy the main parachute when it senses the altitude has decreased to 1500 feet.

As a safety feature, a redundant telemetry and flight control computer is used. This Featherweight Raven 4 device independently measures altitude, and can independently deploy both the drogue and main parachutes. The Raven 4 processor will deploy the drogue parachute three seconds after it has sensed apogee, provided the velocity of the rocket is under 400 feet per second, and the air pressure is increasing. The processor will deploy the main parachute when it senses the altitude has dropped to 1200 feet, the rocket is moving slower than 400 feet per second and the air pressure is increasing.

The two flight control computers are powered by independent lithium polymer rechargeable batteries, as are the redundant charges which can deploy the parachutes. During flight, each computer will consume less than 2% of the energy from a fully charged battery, and can sit idle for dozens of hours if necessary, as show in Table 1. Mechanical safety interconnect switches disconnect all parachute charges from the computers while the rocket is on the ground, to prevent accidental activation.

Table 1: Power Budget

	TeleMetrum	Raven4
Voltage(V)	7.4	7.4
Capacity(mAh)	3500	3500
Energy (Wh)	25.9	25.9
Flight Power Draw (Watts)	.6	.444
Flight Time (Sec)	330	330
Flight Energy (Wh)	.55	.407
Remaining Energy (Wh)	25.32	25.493
Idle Power Draw (Wh)	.32	.148
Idle Time (hr)	79.21	172.25

Paralite Payload

The payload of the rocket consists of three 1U cubesats, referred to as paralites, which will be ejected from the rocket shortly after it deploys its main parachute. Once clear of the rocket, the paralites will each deploy their own main parachute. These parachutes have varying designs: pull-down apex, cruciform and parabolic. Data on the performance of the various parachutes may aid the design teams developing the next generation of these sounding rockets. The paralites will take photographs of their parachutes deploying, and gather GPS based data on location, velocity, acceleration and shock loading. The bulk of the information that will be acquired from the paralites are the drag coefficients and the shock force of the parachutes.

The rocket's payload is a 3U (10x10x30cm) cubesat designed to measure the coefficient of drag and shock force of a pull-down apex, cruciform and parabolic parachutes. This data will help in the design of future parachutes for the team.

A. Payload Bay

The main structure of the payload bay is a 3U (10 cm x 10 cm x 30 cm) welded steel frame, as shown in Figure 4. Each of the three paralites use the same mechanical design, which is a fiberglass enclosure as illustrated in Figure 5. The paralites compress springs when inserted into the payload bay, and it is the force of these springs which will eject them during descent. The flight control computers will activate the solenoids which hold the paralites in place, as the rocket passes an altitude of 900 feet during its descent.

B. Paralites

The physical configuration of the paralites are shown in Figure 6. The paralite avionics system consists of battery, microcontroller, three sensors, a radio transmitter, and power conditioning electronics. Data collection and aggregation is handled by a Teensy 3.6 microcontroller system. In

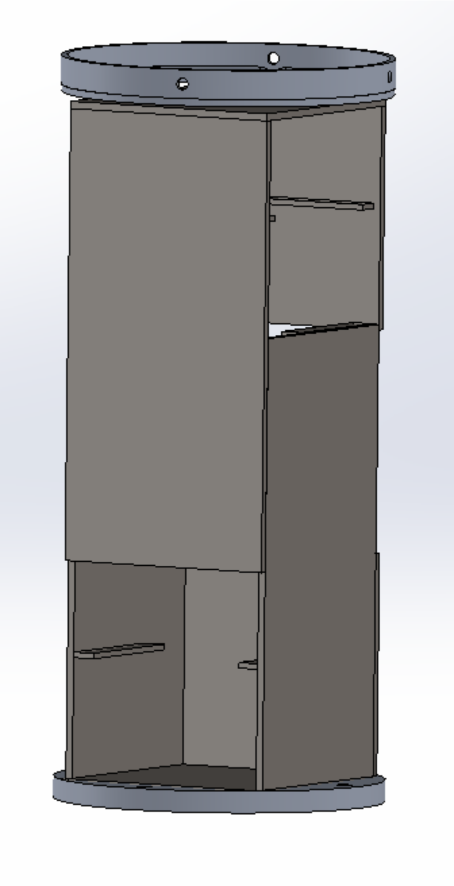

Figure 4: Payload Main Structure

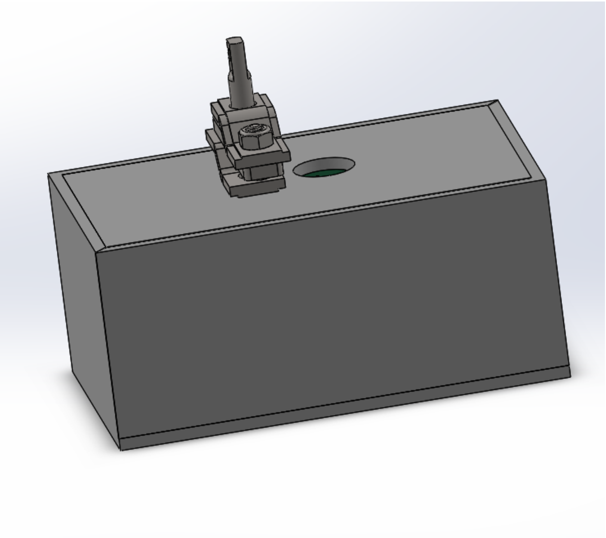

Figure 5: Paralite Structure

addition to handling data, the microcontroller board directly powers the three sensors.

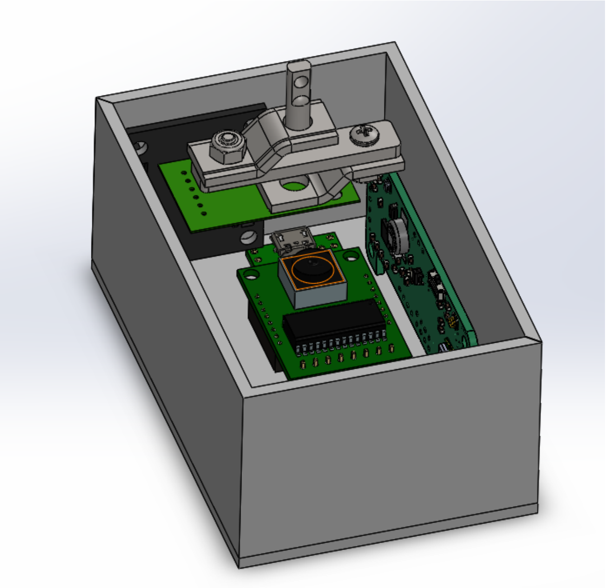

Figure 6: Paralite Internals

Video and still images of the paralite's parachute will be captured by an Arducam 0V2640, 15 frame per second, video camera. A BerryGPS-IMUv4 will send to the microcontroller data from its internal three axis accelerometer, gyroscopes, and magnetometers. In addition it will provide pressure and temperature data, along with GPS coordinates. As shock load is of particular interest to the parachute designers, an HX711 load cell will be used to collect shock loading data.

The data from the various sensors will be stored in an SD memory card inserted into the microcontroller board. To aid in recovery of the paralites, GPS data will be transmitted using an XBee radio module.

The paralite is powered by a 18650 lithium polymer battery. A boost converter produces a constant 5 volts form the variable 3.7 volt battery supply voltage. As shown in Figure 7, the microcontroller board steps the voltage down to the 3.3 volts required for the three sensor packages. A linear voltage regulator reduces the 5 volt supply to the 3.3 volts required for the XBee radio system used to transmit the telemetry data.

SOUNDING ROCKET TELEMETRY SYSTEM

The telemetry system on the sounding rocket is a combination of commercial off the shelf system (COTS), and a student researched and designed (SRAD) system. The SRAD system will allow for higher performance and range, as well as being more adaptable and expandable as the needs of the team evolves over future launches. The SRAD system is particularly important for the paralites. The volume, weight and power constraints on the paralites make the COTS system impractical. In

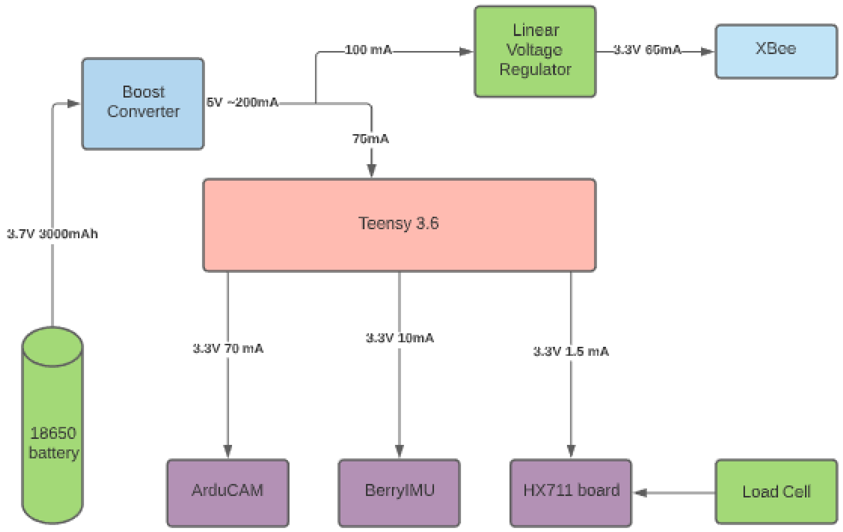

Figure 7: Paralite Power Flow

addition, it may be necessary for the paralite telemetry systems to be initialized by the sounding rocket telemetry system, and relay their data through it. This level of flexibility is not offered by the COTS system the team has been using in past launches.

The COTS system is a Altus Metrum Telemetrum 3.0 device, with an integrated GPS receiver and 440 MHz transmitter. As previous sounding rockets the team wanted to verify the downlink would operate up to the target altitude of 30 000 fee, or approximately 9 km. Our analysis determined the power received by the ground station antennas as a function of altitude, and whether that power is within the sensitivity rating of the receiving radio modules. Our analysis shows the 440 MHz downlink should be useful up to 50 km, as illustrated in Figure 8. The SRAD system will use a transmitter in the 900 MHz ISM band, with a receiving antenna with a 15 dBi gain. Analysis of that link indicates it should also have ample margin at the 9 km apogee of the rocket, as shown in Figure 9.

Previous sounding rockets developed by the team used fiberglass bodies. The telemetry system took advantage of the relative RF transparency of fiberglass, and placed all antennas on the interior of the rocket. Future rocket designs will be based on carbon fiber technology. This complicates telemetry system design, as it forces the use of exterior antennas. In the current design, the nosecone of the rocket continues to be of fiberglass construction, so the telemetry bay was placed in the base of the nosecone as illustrated in Figure 10. The electronics are mounted to a fiberglass sled which is between two aluminum bulkheads.

A 900 MHz patch antenna [4] design is used for the SRAD telemetry system 900 MHz ISM band transmitter. The antenna is currently mounted on the outside surface of the nosecone, but will eventually be moved to the exterior of the conductive carbon fiber composite rocket body. The Berry GPS-IMU device in the rocket is connected to an active GPS antenna mounted on the top of

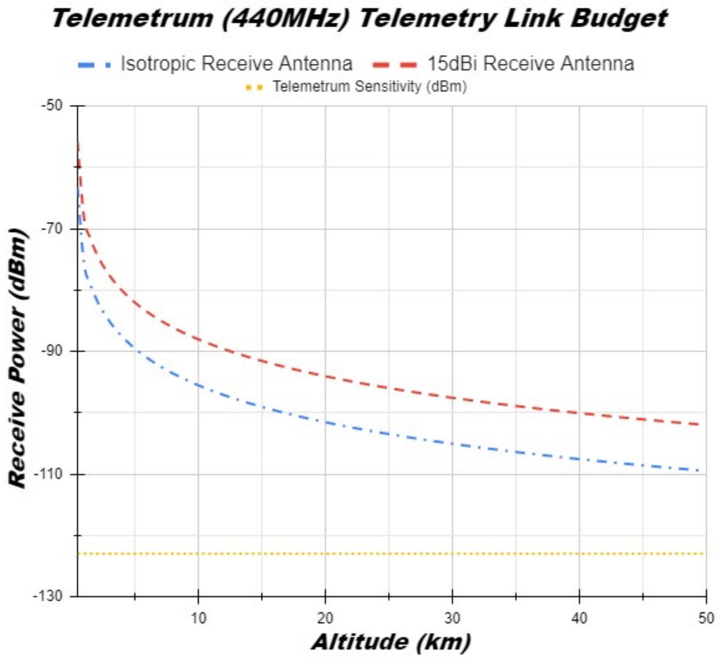

Figure 8: Telemetrum Link Performance

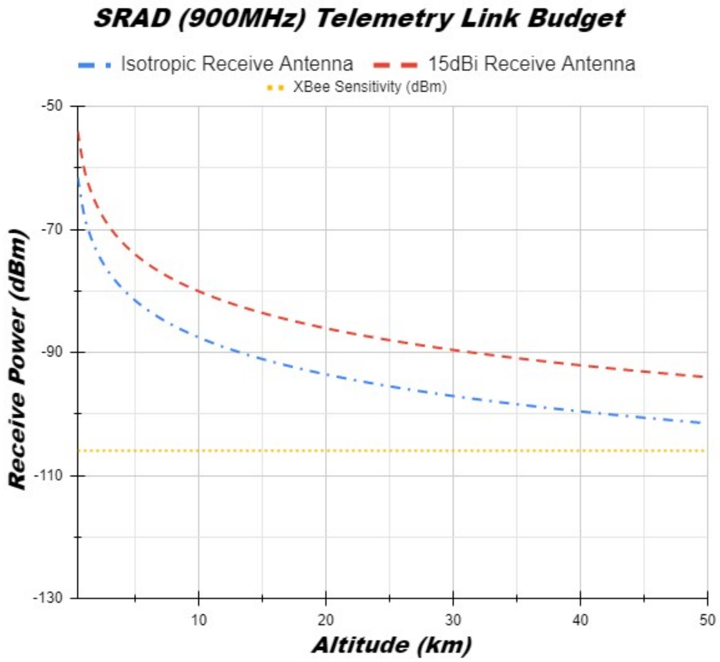

Figure 9: SRAD Link Performance

the telemetry bay in the fiberglass nosecone. This allows for improved reception of GNSS constellations over the internal antenna.

Figure 10: Telemetry Bay CAD Model Showing Location In Nosecone

Prior to deployment, the paralites will be located entirely within the rocket body, and will be unable to transmit or receive RF signals. The team is investigating the possibility of having the GPS receivers of the paralites initialized by the sounding rocket telemetry system, to reduce GPS acquisition time once they are deployed. To keep the paralite design simple and compact, simple wire monopole antennas will be used for their 900 MHz ISM band transmitters, with a ground plane attached to their fiberglass case. The radiating element of the antenna is simply the center conductor of an RG-316 coaxial cable. The insulating material normally covering the center conductor is left on. This allows the antenna to be folded before deployment to save space, and automatically right itself after deployment. The insulation impacts radiation characteristics of the antenna, but we have accounted for that in the antenna design. The fiberglass body of the paralites allow the internal GPS antenna of the Berry GPS-IMU unit to be used, without need to supplement it with an external antenna.

The ground station includes the hardware required to receive the telemetry data from both the Telemetrum on the 440 MHz band and the SRAD system on the 900 MHz band. To achieve optimal reception of the telemetry signals, the team uses both a four element 440 MHz Yagi-Uda antenna, and a nine element 900 MHz Yagi-Uda antenna mounted to a tripod. This setup allows a team member to visually aim the antennas towards the rocket during its flight and keeps the antennas oriented for optimal reception.

The telemetry system needs to help inform the team where the rocket and paralites landed. The Telemetrum receives and interprets a GPS signal and transmits this data to the ground station using its integrated transmitting unit. The SRAD system will be receiving and decoding NMEA 0183 strings [5] from the on-board BerryGPS-IMU module [6], extracting and combining relevant position information from these strings, and sending the data to the ground station. The GPS position data is also stored locally on the telemetry hardware on both the rocket and the paralites for analysis post-flight.

In addition to GPS coordinates, the SRAD telemetry processor will collect data from the accelerometer, gyroscope, magnetometer, barometer, and temperature sensors. This data will be aggregated into on-board storage on both the rocket and the paralites where it will be analyzed post-flight.

The ground station is run off a Raspberry Pi, which was chosen as the computer due to its low power draw combined with its small form factor. This connects to a monitor, USB keyboard, and wireless mouse, providing full functionality. The commercial software set up for programming the altimeters is a AltOS for the telemetrum, and a Featherweight FIP. Both provide the capability to program our altimeters to required conditions and allows the team to communicate with the telemetry system onboard the rocket.

CONCLUSIONS

This paper described the redundant sounding rocket avionics systems based on COTS technology. We also described the telemetry system for both the sounding rocket and deployed paralite array. The legacy COTS telemetry system which worked will in earlier team designs is being replaced by a SRAD system. The smaller footprint of the SRAD system will allow it to be placed in the paralites. The SRAD system on the sounding rocket will provide the team with the flexibility it needs to use the rocket to record and relay data from the paralites, which have a very limited transmitter range.

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REFERENCES

[1] Spaceport America, “Spaceport america cup,” Jul. 2021. [Online]. Available: https://spaceportamericacup.com/

[2] Experimental Sounding Rocket Association, Jul. 2021. [Online]. Available: https://www.soundingrocket.org/sa-cup-home.html

[3] Altus Metrum, “Telemetrum,” Jul. 2021. [Online]. Available: https://altusmetrum.org/index.html

[4] P. J. Bevelacqua, “Microstrip (patch) antennas,” Jul. 2021. [Online]. Available: https://www.antenna-theory.com/m/antennas/patches/antenna.php

[5] National Marine Electronics Association, “NMEA-0183 Standard,” Jul. 2021. [Online]. Available: https://www.nmea.org/content/STANDARDS/NMEA_0183_Standard

[6] Ozzmaker, “BerryGPS-IMU V4,” Jul. 2021. [Online]. Available: https://ozzmaker.com/product/berrygps-imu/