Solar Powered GPS Tracker

Final Report

Semester Project EGR 436

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Table of Contents

Problem Statement / Purpose of Device

This GPS Data logger is designed to be a portable GPS logger. Using information provided by the GPS module, it logs the position of the module into a removable Micro SD card, from which the data can be viewed using a disk editor (such as the freeware HxD). The module incorporates an accelerometer to determine if the module has started moving. This ability is used to drive the module to a low power mode when inactivity for more than a minute is detected, such that the life of the module is maximized. This device is aimed for use in geographic path mapping (such as mapping out a new hiking trail) or in place-and-forget applications where the module can be placed on an object (such as a vehicle) and track the position of that object until the SD card is taken out and the data viewed.

Requirements / Specifications

1. The prototype must use rechargeable batteries.
2. The prototype must log data to nonvolatile memory.
3. The prototype must have an appropriate enclosure.
4. The prototype must have a solar panel.
5. The prototype must be capable of charging through USB
    5.1. The prototype must prevent over voltage of batteries when utilizing USB Charging.
6. The prototype must implement an appropriate solar charge circuit.
    6.1. The prototype must stop charging from solar if being charged through USB.
7. The prototype must utilize a custom PCB.
8. The prototype must contain a GPS module.
9. The prototype may contain an accelerometer.
10. The prototype must be capable of monitoring battery voltage.
    10.1. The prototype must cut-off battery power draw when the battery is discharged.
11. The prototype must be capable of monitoring battery current draw.
    11.1. The prototype must detect over current conditions.
12. The prototype may implement a low power operation state.
    12.1. The prototype may disable GPS reading while in low power.
    12.2. The prototype may store unflashed GPS data to nonvolatile memory when entering a low power state.
    12.3. The prototype may disable bluetooth in a low power state.
    12.4. If in a low power operation state, the prototype may be wakeable from the low power state.
13. The prototype must implement an active operation state.
    13.1. The prototype must log GPS data while in an active operation state.
    13.2. The prototype must allow bluetooth connections while in active operation state.

13.3. The active operation state may be triggered by accelerometer data.

13.4. When in an active operation state, the prototype must store GPS data every five minutes.

14. The prototype must protect against reverse polarity connection of batteries.

    14.1. The prototype may use a reverse polarity protection diode and fuse.

15. The prototype must be capable of communicating via low energy bluetooth.
16. The prototype must be capable of communicating via USB.
17. The prototype must have a method for attaching to surfaces.

    17.1. The prototype may attach to magnetic surfaces.

    17.2. The prototype may use magnets, velcro, glue, brackets, or other methods for attaching to surfaces.

Verification

1. The prototype must use rechargeable batteries.
   - ***Prototype uses Li-Ion battery and charging circuit in tandem.***
2. The prototype must log data to nonvolatile memory.
   - ***Saved data to SD card, data is viewable using disk editors, like HxD. Screen snip below of what HxD finds in SD card after some reads.***

```
Decoded text
$GPGSV.,493645.004,1455.737546,24076.692274,0.141,5105.,360421,21
$GNGGA.,193647.001,N255.737411,W4076.692271,12141,1.05.,198.31,MI
$GLGSV.,393647.001,0955.737415,03076.692278,12141,7205.,058.31,01
$GNGSA.,A93647.003,1455.737410,17076.692278,01141,1905.,218.31,01
$GLGSV.,393647.002,0955.737410,34076.692274,31141,8105.,748.31,00
$GNGSA.,A93647.003,7955.737418,81076.692272,80141,8105.,748.31,00
```

Figure 1: Decoded Text

3. The prototype must have an appropriate enclosure.
   - ***Prototype has an enclosure, made waterproof using epoxy at possible water entrances. See photo of enclosure below.***

Figure 2: Enclosure

4. The prototype must have a solar panel.
   - ***Prototype enclosure has a solar panel fixed to the lid, see photo from above.***
5. The prototype must be capable of charging through USB
   5.1. The prototype must prevent over voltage of batteries when utilizing USB Charging.

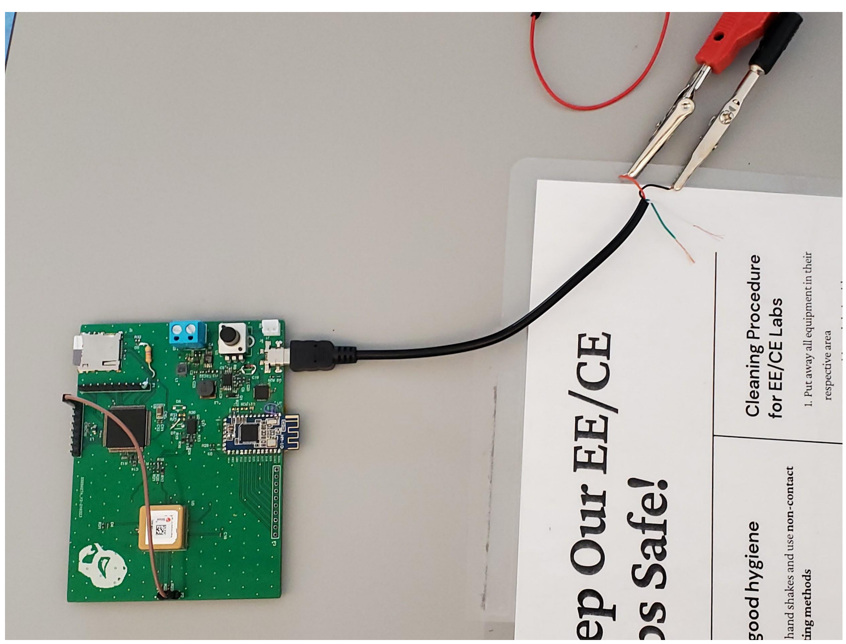

Figure 3: No Battery Test Setup

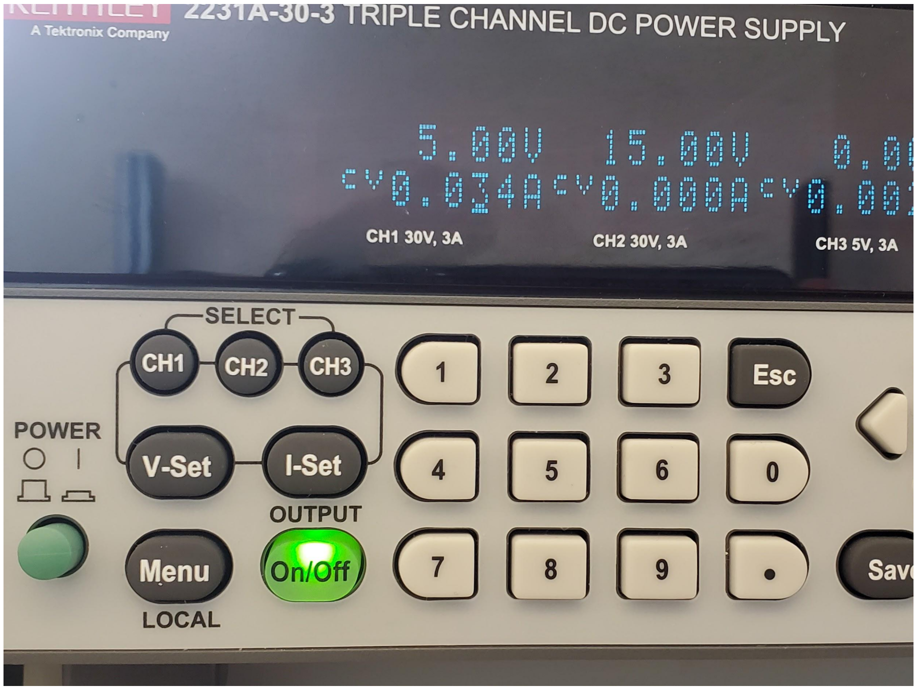

Figure 4: No Battery Current Draw

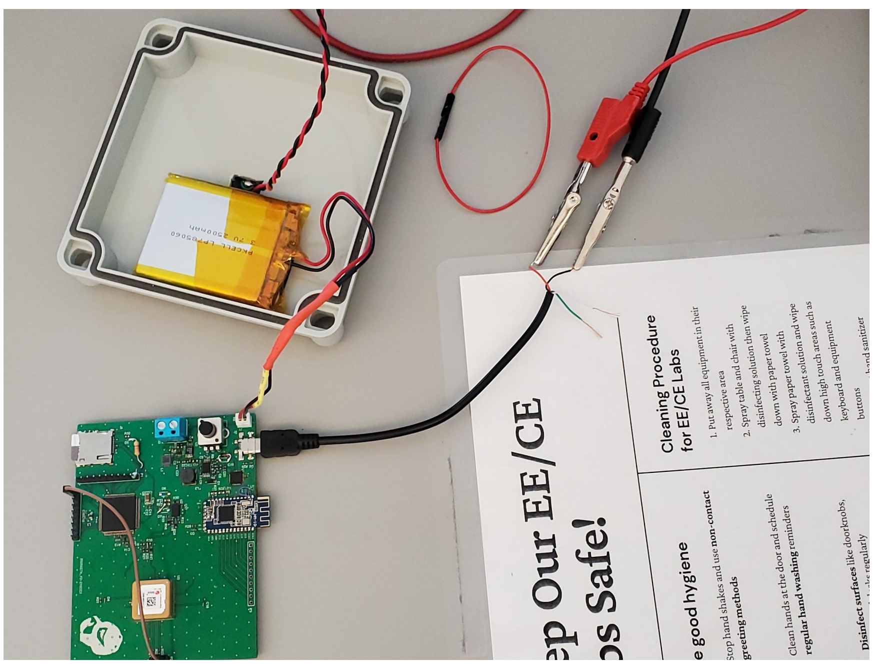

Figure 5: Battery Connected Test Setup

Figure 6: Battery Connected Current Draw

6. The prototype must implement an appropriate solar charge circuit.
   - ***An MPPT IC (SPV1040TTR) is implemented to get as much power from the power sources as possible. It takes in voltages of a range from 0.3 [V] to 5.5 [V], which suits the needs of this design.***

   6.1. The prototype must stop charging from solar if being charged through USB.
   - ***The voltage provided by USB is greater than that provided by the solar panel. By design, diodes are placed on the USB and Solar Panel voltage lines feeding into the MPPT that make it such that no current flows from the solar panel if a USB connection is providing 5 [V]. This stoppage of current from the solar panel is due to the higher voltage being present on the cathode of the diode on the solar panel power line.***

7. The prototype must utilize a custom PCB.
   - ***A custom PCB is used, see photo below.***

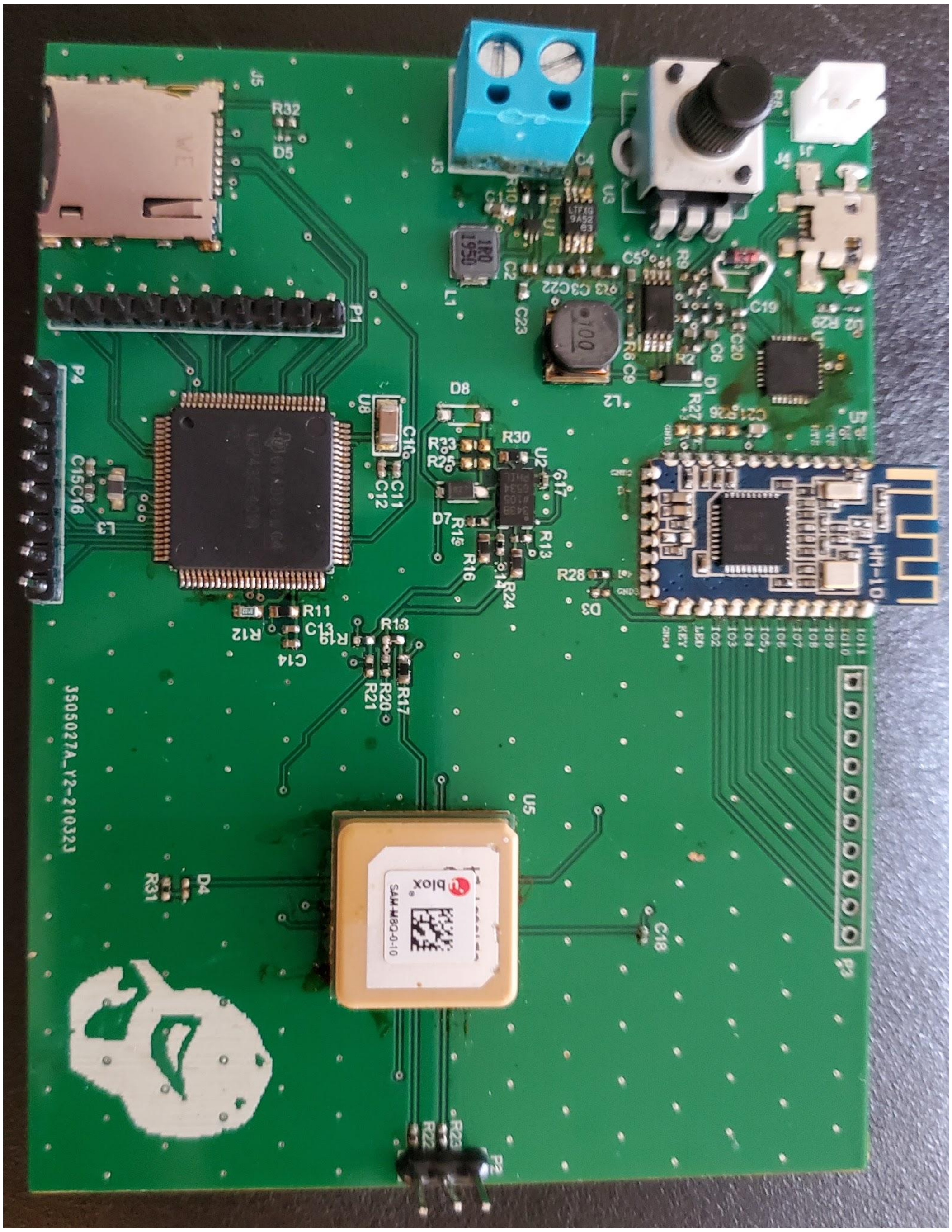

Figure 7: Picture of Custom PCB

8. The prototype must contain a GPS module.
   - ***The custom PCB uses the SAM-M8Q. From inspection of the datasheet, it is a GPS module.***
9. The prototype may contain an accelerometer.
   - ***The custom PCB uses the ADXL-343. From inspection of the datasheet, it is a GPS module.***

10. The prototype must be capable of monitoring battery voltage.
    10.1. The prototype must cut-off battery power draw when the battery is discharged.
        - ***The design makes use of a battery monitoring charging circuit. The IC responsible for this is configurable to stop battery current draw when the voltage is at or lower than the configured discharged voltage.***
11. The prototype must be capable of monitoring battery current draw.
    11.1. The prototype must detect over current conditions.
        - ***The module does not monitor battery current draw directly. A next revision should have a current sense resistor and/or IC to perform this function. This information would then be provided to the microcontroller so that it can respond accordingly.***
        - ***The MP2152GQFU-33-P, which is the switching power supply IC, does have short circuit fault detection and will stop outputting voltage for as long as it detects this condition. Once the fault is fixed, it will start up normally and output its regulated voltage.***
12. The prototype may implement a low power operation state.
    12.1. The prototype may disable GPS reading while in low power.
        - ***The module does not read from the GPS when in low-power state and puts the SAM-M8Q into low power mode via its external interrupt pin.***
    12.2. The prototype may store unflashed GPS data to nonvolatile memory when entering a low power state.
        - ***The module does not go into sleep mode until it has finished reading a message from the GPS module. This way, complete messages are stored in the MSP prior to going into low-power mode.***
    12.3. The prototype may disable bluetooth in a low power state.
        - ***Prototype does not implement a low-power state for the HM-10 BLE module***
    12.4. If in a low power operation state, the prototype may be wakeable from the low power state.
        - ***The prototype "wakes" on detection of movement as indicated by the accelerometer.***
13. The prototype must implement an active operation state.
    13.1. The prototype must log GPS data while in an active operation state.
        - ***See verification of requirement 2.***
    13.2. The prototype must allow bluetooth connections while in active operation state.
        - ***Connection via bluetooth is possible, see the data sent via bluetooth below after connection with phone.***

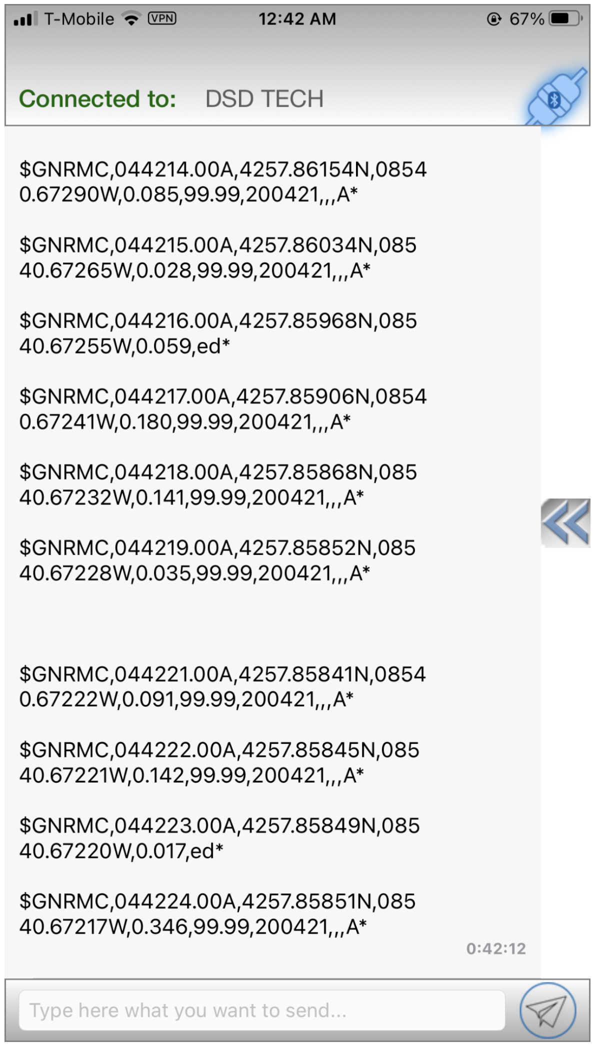

Figure 8: Serial Data from module as seen via bluetooth sniffer app

13.3. The active operation state may be triggered by accelerometer data.

- ***Current software setup checks the registers of the accelerometer component to see whether it is in sleep or active mode. Active state of the module is triggered when the accelerometer comes out of sleep mode into active mode.***

13.4. When in an active operation state, the prototype must store GPS data every five minutes.

- ***Current operation stores messages after every 7 complete messages are read from the GPS module in an active state. This makes the readings more frequent than every 5 minutes, and especially so since several sets of messages are saved every active period of the module (with each active period lasting 1 minute). In a next revision, this requirement would be reworded to say that it should save with a frequency of at least every 5 minutes.***

14. The prototype must protect against reverse polarity connection of batteries.

14.1. The prototype may use a reverse polarity protection diode and fuse.

- ***Current design uses a keyed JST connection, such that the battery can only be connected in one direction. A user would have to actively be trying to connect a voltage source the wrong way (bypassing safety implementations) to connect it incorrectly.***

15. The prototype must be capable of communicating via low energy bluetooth.
    - ***See verification of requirement 13.2***
16. The prototype must be capable of communicating via USB.
    - ***Data is sent via UART to a UART-to-USB converter IC. This data can be seen in a serial terminal (such as TeraTerm) or another serial monitor program. See unformatted data below.***

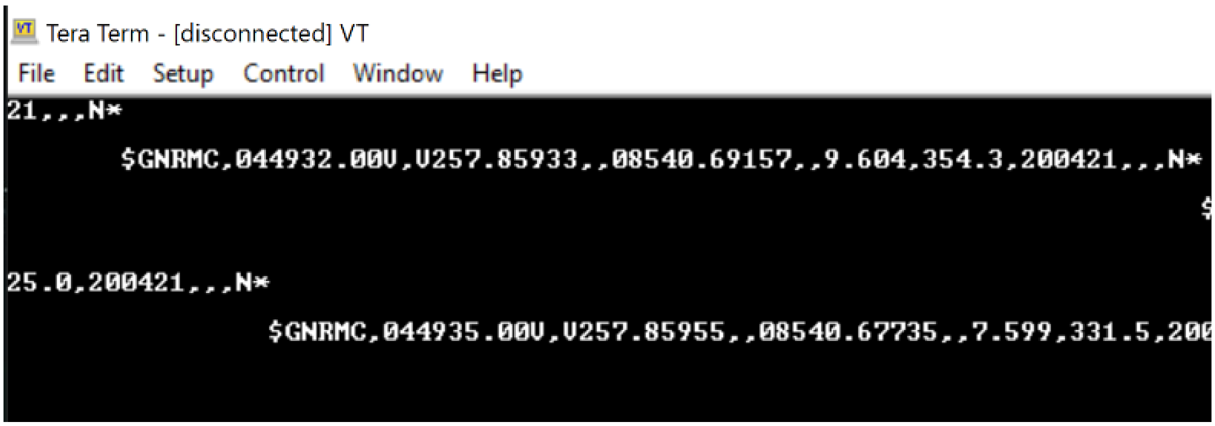

Figure 9: Serial Data from module as seen via Tera Term

17. The prototype must have a method for attaching to surfaces.
    17.1. The prototype may attach to magnetic surfaces.
    17.2. The prototype may use magnets, velcro, glue, brackets, or other methods for attaching to surfaces.
    - ***Prototype makes use of a magnet attached to the enclosure to stick to magnetic surfaces. See picture below.***

Figure 10: Picture of Magnet on Back of Enclosure

Design

Bill of Materials

Table 1: Bill of Materials

Designator	Description	Value	Manufacturer P/N	Price	Quantity
BT1	Adafruit Accessories Lithium Ion Polymer Battery 3.7V 2500mAh	-	328	$14.95	0
C1	Capacitor X6S 0402 (1005 Metric)	22uF	GRM155R60J106ME05J	$0.52	1
C2, C3, C4, C5, C6, C7, C22, C23	Capacitor X6S 0402 (1005 Metric)	10uF	GRM155R60J106ME05J	$0.15	8
C8, C18, C20	Capacitor X6S 0402 (1005 Metric)	1uF	GRM155R70J105KA12J	$0.11	3
C9, C11, C12, C13, C14, C15, C17, C19	Capacitor X6S 0402 (1005 Metric)	0.1uF	GRM155R71H104KE14D	$0.10	8
C10	1206 Polarized Chip Capacitor - Standard	10uF			1
C16	Capacitor X6S 0402 (1005 Metric)	4.7uF	C1005X5R0J475K050BE	$0.43	1
C21	Capacitor X7R 0402 (1005 Metric)	0.1uF	0402YC104JAT2A	$0.72	1
D1	Schottky Diodes & Rectifiers REC SPCL SKTKY		SBR80520LT1G	$0.43	1
D2, D5	Standard LEDs - SMD 0201 SMD LEDs 520nm Green		SML-LX0201UPGC-TR	$0.47	2
D3, D4	BLUE - Standard LEDs - SMD 1.0X0.5MM		APHHS1005LQBC/D-V	$0.56	2
D6, D7	Schottky Diodes & Rectifiers REC SPCL SKTKY		1N4148	$0.43	2
J1	Connector Header Through Hole 2 position 0.079" (2.00mm)		B2B-PH-K-S(LF)(SN)	$0.17	1
J3	Fixed Terminal Blocks Terminal block, screw type, 5.00, horizontal, 2 poles, CUI Blue, slotted screw, PCB mount		TB001-500-02BE	$0.58	1
J4	USB Connectors USB 2.0 micro B jack 5 pin HZ mid-mnt SMT			$1.05	1
J5	Memory Card Connectors WR-CRD_SMT_MicroSD_Push & Push - SW closes to ground		693071030811	$3.76	1
L1	Shieled Power Inductor	1uH	74437324010	2.20	1
L2	Fixed Inductors 10uH 56.4mOhms3.1A +/-20% 6.3x6.3x4.5mm	10 uH	1255AY-100M=P3	$0.47	1
L3	Fixed Inductors 0805 4.7uH +/-30% 30MHz 0.8A 0.23ohms	4.7uH	LQM21PN4R7NGRD	$0.32	1
P1, P3	Header, 10-Pin				2
P2	Header, 3-Pin				1
P4	Header, 8-Pin				1
R1, R10	Resistor, 0402 Package size	100k		$0.12	2
R2	Resistor, 0402 Package size	10m		$0.39	1
R3, R11, R16, R17, R24, R26, R27, R30		0	CRCW06030000Z0EA	$0.10	8
R4	Resistor, 0402 Package size	1M		$0.14	1
R5, R6, R7	Resistor, 0402 Package size	1K		$0.14	3
R8	Potentiometers PANEL CONTROL - 9MM-ST-CA 100 kohms 15 mm	100k	PTV09A-4015U-A104	$0.79	1
R9	Resistor, 0402 Package size	422k		$0.10	1
R12		91k	TNPW060391K0BEEA	$1.28	1
R13, R14, R15	Resistor, 0402 Package size	10k		$0.12	3
R18, R19	Resistor, 0402 Package size	2.2k		$0.23	2
R20, R21	Resistor, 0402 Package size	22		$0.22	2
R22, R23	Resistor, 0402 Package size	470		$0.23	2
R28, R29, R31, R32	Resistor, 0402 Package size	390		$0.10	4
U1	Switching Voltage Regulators 5.5V,2A,Sync Step-Down Converter with 25A IQ and Output Discharge in QFN and SOT563 Packages		MP2152GQFU-33-P	$1.45	1
U2	Accelerometer X, Y, Z Axis ±2g, 4g, 8g, 16g 0.05Hz ~ 1.6kHz 14-LGA (3x5)			$3.10	1

Description of Software Execution

The program is made to interface with an accelerometer (ADXL 343), a GPS module (SAM-M8Q), and high-capacity (32 GB) MicroSD card to log positional data of the module. On startup, the program goes through an initialization process for each major component of the system: the gps module, the accelerometer, and the SD card.

After power-up and initial MSP setup, there is a necessary 1 second delay prior to any SD card initialization to allow for the SD card to stabilize after first power up. Once complete, the SD card initialization process is started. This initialization process is used for high-capacity Micro SD cards. The initialization process involves sending through SPI interface with the SD card a set of command packets. If this process fails, the SD card remains in idle mode and cannot be written to or read from. As such, it is imperative that only high-capacity cards be used with this version of the code and prototype. Later revisions should include the ability to work with a wider variety of SD cards, not just high-capacity cards. Once the SD card initialization process is complete, setup of the other modules begins.

The GPS module only requires an I^2C communication to be set up in order to speak to it. The accelerometer also uses this I^2C bus. During the initialization process, the registers of the accelerometer are configured to create an exclusive Active → Inactive → Active flow of states, which is the desired behaviour. The sensitivity of the accelerometer is also adjusted. During the PCB soldering process, the sensitivity of the IC may be changed due to the electromechanical springs used in detecting acceleration within the IC, so this value may need to be adjusted in code on a per-module basis. Future code revisions should allow for input from a user to adjust this value as necessary.

The accelerometer is used to detect motion. When motion is detected, the module becomes active, waking the GPS module from low power mode. Once the SAM-M8Q is ready, it is hailed for positional data. It is expected that the SAM-M8Q module is already configured such that it only sends NMEA RMC messages through I^2C communications. Later revisions of this module may include the ability to send configuration messages to the GPS module to create this setup. Currently, the setup is configured externally via U-Center software provided free of charge by U-Blox.

After becoming active, the system is kept active for 1 minute. During this time, GPS data is stored in the SD card after 7 complete messages are read by the microcontroller from the GPS, which can be viewed via disk editors, such as HxD. The system also displays the data being saved in real time via USB serial port and Bluetooth Low Energy (BLE). After 1 minute has passed, if no further activity is detected and if the system is not in the middle of reading an RMC message from the SAM-M8Q, then the system goes into sleep mode, putting the GPS module into a low power mode. It then stays in this state until the accelerometer detects motion, which causes the cycle to repeat.

One thing to note, the I^2C modules (particularly the ADXL 343) become confused any time I^2C communication is interrupted mid-operation. In order to allow for a safe stop of the code for the purpose of downloading new firmware to the module, one pin of the MSP is configured as an input with a pull-up resistor. In order to allow the software to operate freely, this pin must be grounded, making that input read low. On the current prototype, this is done through a jumper wire. However, future hardware revisions should be made with an external toggle switch that would connect this input to ground to make it much easier to prepare the software for programming without causing the I^{2}C modules to become confused.

PCB Design

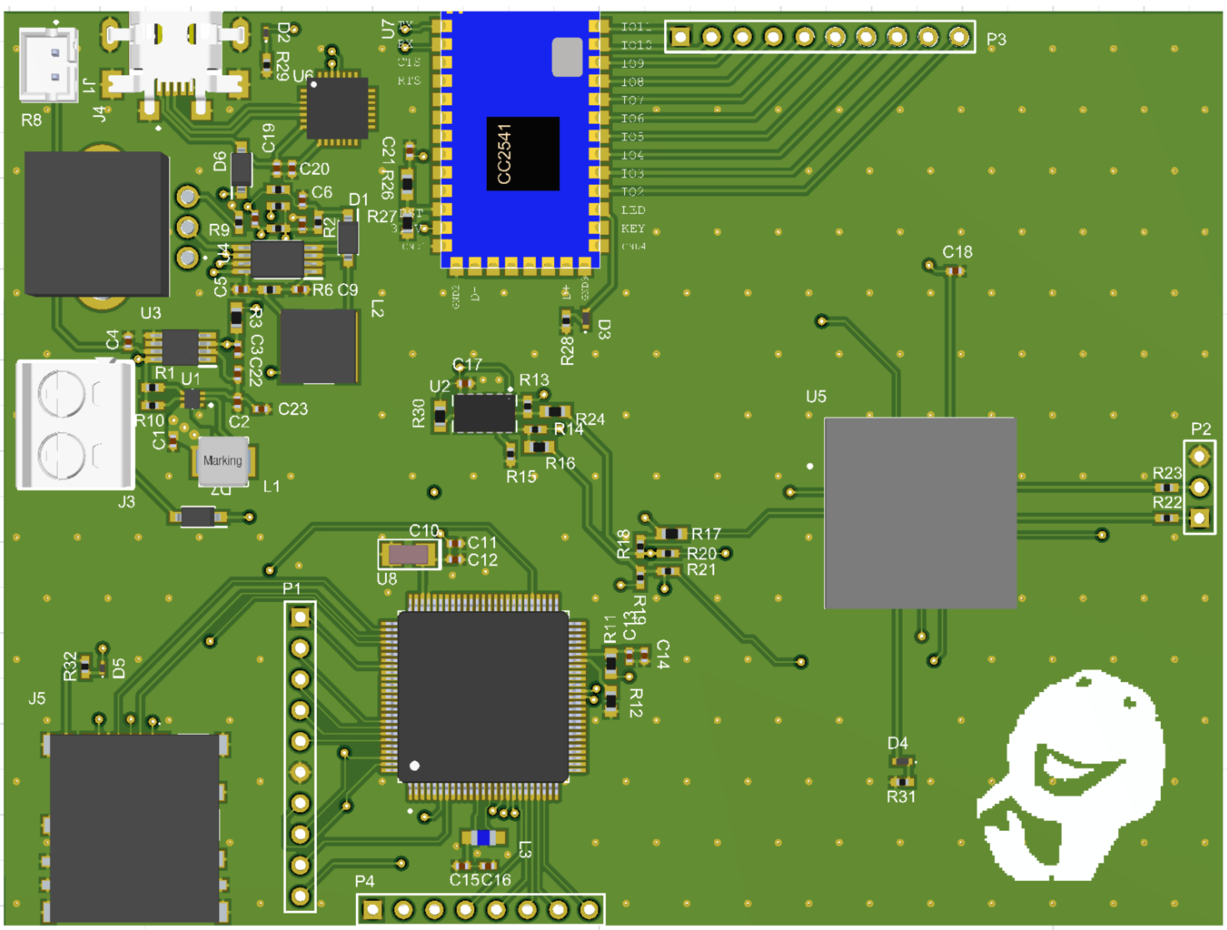

Figure 11: 3-D Render of Board

The PCB design was fairly straightforward. Some careful considerations were needed to ensure the SAM had the required spacing. The SAM requires a 50mm by 50 mm ground plane beneath it so that the integrated ceramic antenna can function properly. There is also a recommended part keep out and signal via keep out of 10mm around the part package. This may have been violated by some of the vias, but the SAM still functions properly. The other design consideration was the location of the HM-10 module, it was necessary to keep it far away from the SAM which led to the placement it currently has. The ADXL should likely be moved closer to a mounting point as recommended by the datasheet. It would be better to remove the headers in the future. The stitching via spacing was chosen based on the bluetooth frequency, 2.45 GHz. So:

$$\lambda = \frac{C}{f\sqrt{\mu_r \epsilon_r}}$$
$$= \frac{3 \times 10^8}{\sqrt{(1)(4.4)}(2.45 \times 10^9)}$$
$$\lambda = 58.38 \text{ [mm]}$$
$$\frac{\lambda}{10} = 5.838 \text{ [mm]}$$

5.838 [mm] was rounded down to 5.00 [mm] on the board when the stitching was applied.

Changes for next revision

As mentioned before, the next revision of hardware should include a toggle switch connecting one input of the MSP to GND. This would allow for the software to be stopped from running while the switch is connected to ground, such that I^2C communications are not interrupted mid-operation, confusing the ADXL 343 or SAM-M8Q. The pins of the BLE module also do not need to be brought out and should instead be replaced by GPIO of the MSP or additional GND and 3v3 pins. The magnet of the module can also be attached in a more permanent way. The current revision uses epoxy to hold the magnet to the enclosure, but this type of mounting isn't necessarily suitable if the module is to be stressed. A next revision should drill a hole into the enclosure for a screw to go through the center of the magnet and through the hole, which would then be tightened down with a bolt and washer. This would make it much harder for the magnet to come off from the prototype.

Another possible way to improve the design is to swap out the GPS module with another that has an antenna external to the module. The current SAM-M8Q has an internal ceramic patch antenna it uses to receive GPS data, but this antenna requires a solid ground plane underneath it free of other components to work effectively. This created the need for a lot of board space. If the antenna can instead be made external, then the board could be shrunk. Alongside this improvement, it was missed in the original design that the memory of the SAM-M8Q module is actually battery-backed up RAM. Thus, if the RAM loses power, any configuration data is lost and is reset to default. Because the module is supposed to be kept powered after configuration, it is not a big issue, but future revisions should include a separate, dedicated battery (like a coin cell) to keep the RAM powered and not lose any configuration data.

Concerning the software, future revisions should allow for any type of Micro SD card to be used. The proposed hardware-controlled software hang up from above may also be done via PC or BLE command. The initialization process for the SD card is performed at a decent frequency in the kHz range, but SD card documentation claims that after initialization, the clock of the SPI interface can be sped up to be within the MHz range. This was not tested in this revision due to knowing that the slower clock speed worked, but can be tested in future revisions if it is deemed necessary to speed up the general interface. The setup of the ADXL registers should also be made such that the sensitivity of the ADXL can be adjusted. As mentioned before, the sensitivity of the electromechanical springs within the IC can be affected and altered during the soldering process, such that there may be some variation in sensitivity from one module to another. Creating a way for this to be altered after initial configuration would be a good investment. The ADXL should also be mounted near mounting holes to limit vibrations.

Additionally, the board should include mounting holes to make the assembly process easier. This would work well with standoffs and would be a more professional solution than the velcro tape used in the prototype.

The power circuit should also be modified to better handle the 5V in via USB and the low voltage from the solar panel. Because of the current parts specified, a 1N4148 was required in series with the 5V in from USB because its forward voltage drop prevents over voltage on the input to the MPPT. The solar panel should also likely be larger to be able to charge the battery effectively, because at its current size it is insufficient to keep up with power consumption in a lot of cases. This means the battery must be topped off via USB occasionally. The HM-10 could be replaced with custom bluetooth circuitry, or a microcontroller with onboard bluetooth could be chosen.