RETRIEVABLE, LOW-COST RADIOSONDE

By

Khushboo Jain

Lake Boddicker

Raunak Barnwal

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TA: Yamuna Phal

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Abstract

Radiosondes are instruments used to make in-situ measurements of the Earth's troposphere by scientific organizations such as the NWS (National Weather Service). They are typically launched with high altitude balloons to make measurements of temperature, pressure, humidity and wind during their ascent. When the radiosonde lands back to the ground, it often remains perfectly functional. However, these high cost instruments are rarely made retrievable.

This project features the electrical design for a radiosonde that offers tracking functionalities. The radiosonde is tracked with GPS (Global Positioning System). The radiosonde can be interfaced through a cellphone and the instrument described in this project is relatively low cost. In addition to this, the design features the ability to interface various different types of sensors to provide researchers customizability in their experiment.

Contents

1. Introduction

1.1 Problem Statement and Purpose

Radiosondes are instruments commonly known as “weather balloons”. These instruments are used as in-situ devices to sense and transmit information on pressure, temperature, wind at different altitudes in the atmosphere. This data is used to produce a weather “sounding” which helps forecasters and atmospheric scientists understand the daily weather, the fluid dynamics and thermodynamics of the lower layer of the atmosphere known as the troposphere.

Radiosondes are launched in 92 different locations in the United States. The density of this radiosonde network is limited by the high cost associated with each launch (upwards of $300 each). For example, for Champaign, IL, the closest launch-site is in Lincoln, IL. If the radiosonde network were denser, the resolution of temperature, pressure and wind data provided to forecasters would increase. Forecasters would be able to make more accurate and timely weather forecasts. This would have a great impact on the prediction of severe weather that could prevent major economic damages as well as the loss of life and offer overall better and timely preparedness to severe weather disasters that have in previous times resulted in economic losses in the U.S. to the order of millions of dollars.

This design offers additional features aimed at reducing the cost of the instrument as well as adding tracking functionality on the device via GPS. The radiosonde described here can be controlled wirelessly through a cellphone. In this project we explore the viability of a tracking functionality and also aim to reduce the high cost of the instrument. Finally, we are able to demonstrate a fully functional, trackable and low-cost radiosonde.

1.2 Subsystems

This project features several subsystems that are interfaced through the control unit, shown in Figure 1 below.

- **Sensor Unit** – This unit features the instrument’s sensors (thermistor, barometer and altimeter) used to sense ambient conditions while the radiosonde is collecting data from the environment.
- **Memory Unit** – The memory unit is used to store the data measured by the sensor unit onto a microSD card in the .csv (comma separated values) format.
- **GPS Unit** – The tracking unit is comprised of a combined GPS and GSM module. The GPS component acquires the GPS location of the device and the GSM component relays that information back to the user. Additionally, the GSM unit receives a command to trigger the Identification Unit and relay battery status information to the user.
- **Identification Unit** – The identification unit consists of speakers and LEDs. The purpose of this unit is to narrow down the location of the radiosonde when in close proximity i.e. at the GPS location indicated by the GPS coordinates. The unit will receive a command from the control unit to emit a loud noise and a bright light.
- **Control Unit** – The control unit is comprised of the microcontroller and supporting components. The ATMega2560 chip is used for this project.

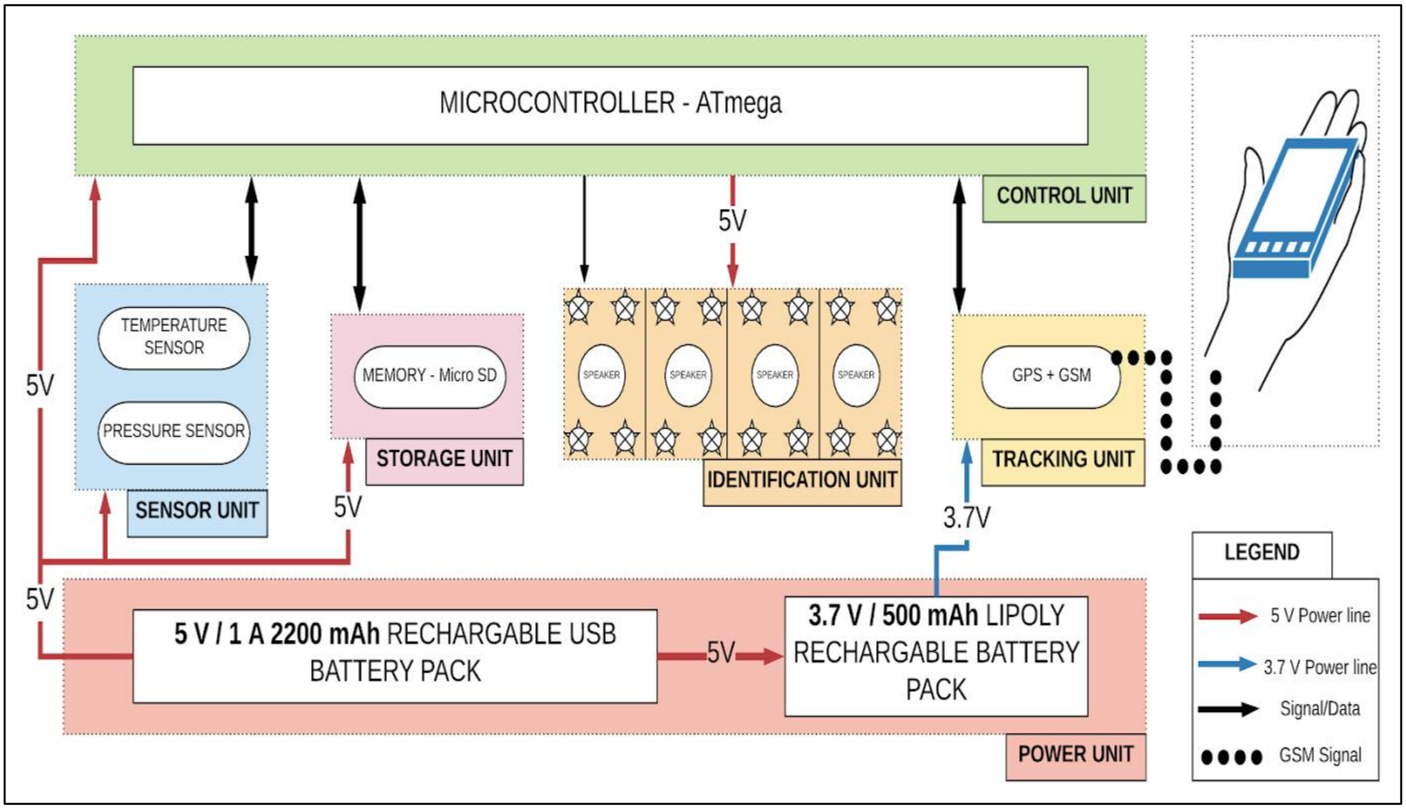

Figure 1: Block diagram

2 Design

2.1 Identification Unit

The identification unit includes a speaker and LEDs. The unit provides audio and visual aid to narrow down the location of the radiosonde after receiving the GPS coordinates. The components are triggered by an 'ALARM' command from the control unit to emit a loud beeping sound and emit flashing bright lights. The LEDs and speakers are located on all four sides of the radiosonde so that light and sound is projected in all directions. These units are powered with a dedicated 9V battery. The alarm is triggered for 15 seconds and then stops to conserve power. The trigger command can be sent through the cellphone key '2'.

2.1.1 Circuit Schematics

a.) b.)

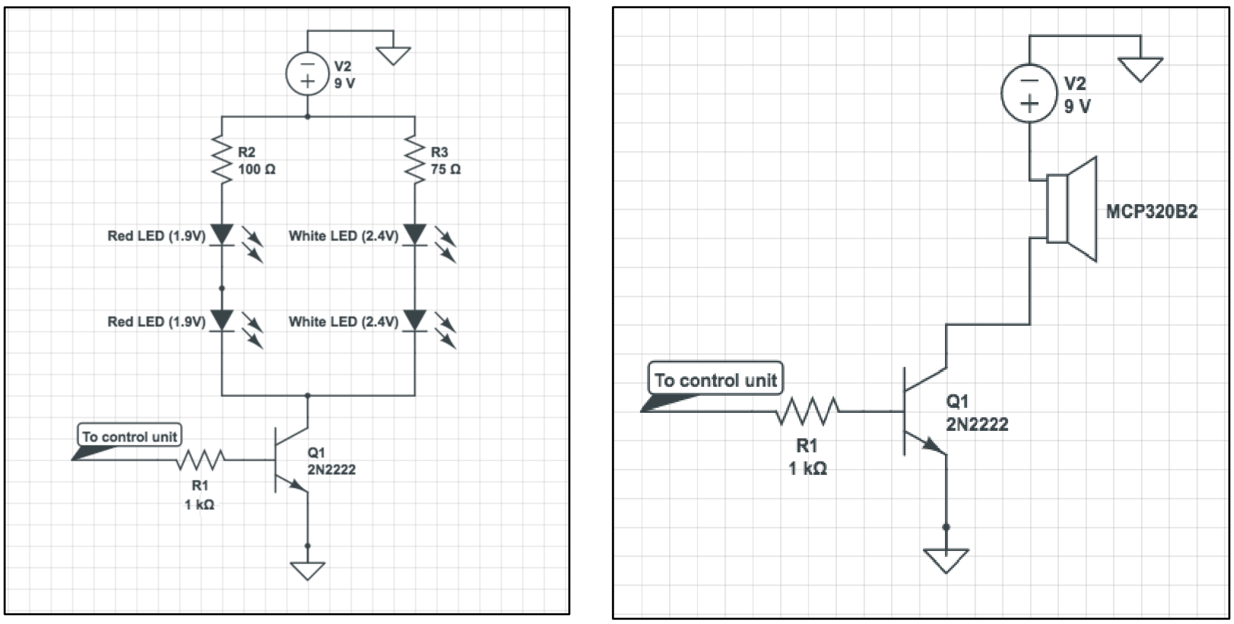

Figure 2: a.) LED and b.) speaker implementation

2.1.2 Calculations

Measured Voltage from 9V battery	8.87 V
Measured Vf (White LEDs)	2.4 V
Measured Vf (Red LEDs)	1.9 V
Imax through LEDs	0.04 A

Table 1: Calculation Parameters

$$\frac{8.87-2(\mathrm{Vf})}{0.04\ \mathrm{A}} = \mathrm{R2}+25, \mathrm{R3}+25\ [\Omega] \tag{1}$$

2.2 GPS and GSM Unit

The GPS and GSM unit are contained inside the FONA808. The FONA808 is an off-the-shelf module that was bought and used for this project. We also considered the option of using a long-range FM transmitter and receiver. However, doing so would have required the difficult challenge of designing and building a transmitter and receiver powerful enough for our purposes or we would have had to deal with the expensive purchase of already built module. It would have also meant that we would have to obtain necessary clearance from the FCC to transmit over long distances. For these reasons we decided to use the FONA808 as it was inexpensive, capable, and compliant will all FCC regulations already.

It should additionally be noted that using the FONA808 required a separate lithium-ion battery due to micro current spikes. It also required use of the AT command set for sending and receiving commands.

We decided to connect it directly to the microcontroller board using female pin headers. Figure 3 below is a schematic of the connections that were made on the PCB to the FONA. These connections enabled power and communicated between the microcontroller and the FONA.

2.2.1 Connection Schematic

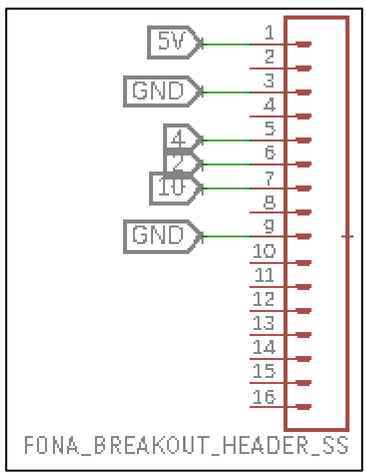

Figure 3: GPS and GSM Unit Connection Schematic

2.3 Sensor and Storage Unit

The Sensor and Storage unit were comprised of an SD card with a breakout board for the storage component as well as a pressure and temperature sensor. The pressure and temperature sensor came in the form of the MPL3115A2 sensor. This sensor is on a single chip and is home to both a pressure and temperature sensor. It allowed us to easily take radiosonde measurements. There are many other existing sensors or sensor chip. The MPL3115A2 was chosen due to its small size, low power draw, low cost, and relative accuracy.

It was impractical to send data using a GSM network at it would be prohibitive data wise. Furthermore, the microcontroller does not have enough memory to store data by itself, thus an external storage solution was needed. The SD card was chosen as it made possible the storage of a large amount of data and was easily read by computers. Furthermore, we choose to store the data in a CSV format so that it could be easily read from using programs such as MATLAB or python.

2.4 Control Unit

The control unit is responsible for reading from and controlling the different modules of our design. For the microcontroller we chose the ATmega2560 over its cheaper and more accessible counterpart, the ATmega328, due to the needs of our device. Our microcontroller needed to communicate with a total of four different systems, a computer for debugging, the sensor, the storage, and the FONA. Each of these connections requires different hardware connections. The ATmega2560 has 100 pins and 3 dedicated UARTs and well as other connections. The ATmega328 has a total of 28 pins and only one UART. This made the ATmega2560 the better choice. Furthermore, that size of our code and all included libraries was quite large. The ATmega2560 has four times the storage as the ATmega328 and thus was again the better choice.

The ATmega2560 necessitated a few different design decisions. First, it needed to be broken out on its own PCB. It a SMD component with a QFP package, this meant that special care would need to be taken with soldering the device. Furthermore, it needed to connect to all the other components and be programmable while on the board itself. It also, of course, needed to be able to run on the board. This meant that supporting circuitry was needed such as decoupling capacitors, and resonators. Figure 4 below shows a schematic of the ATmega2560, the supporting circuitry, and its connections.

2.4.1 Control Unit Schematic

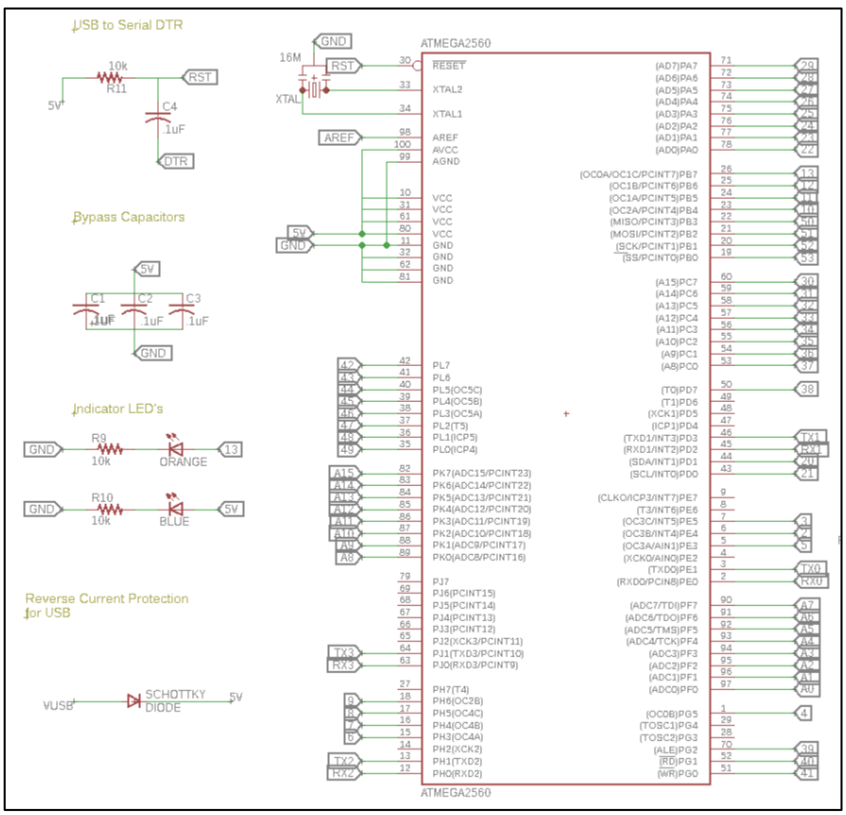

Figure 4: Schematic of Control Unit

2.5 Physical Design

Our sensors and components will all be housed in a Styrofoam payload box that has speakers and LEDs on the external faces. Each face has four LEDs (one for each corner) and a small speaker in the middle. The payload will be tied to a Helium balloon and allowed to ascend into the atmosphere for data collection. Tethered in between the balloon and the payload is a parachute which will serve to retard the payload's descent rate and ensure safe landing. The same is shown in Figure 5 below.

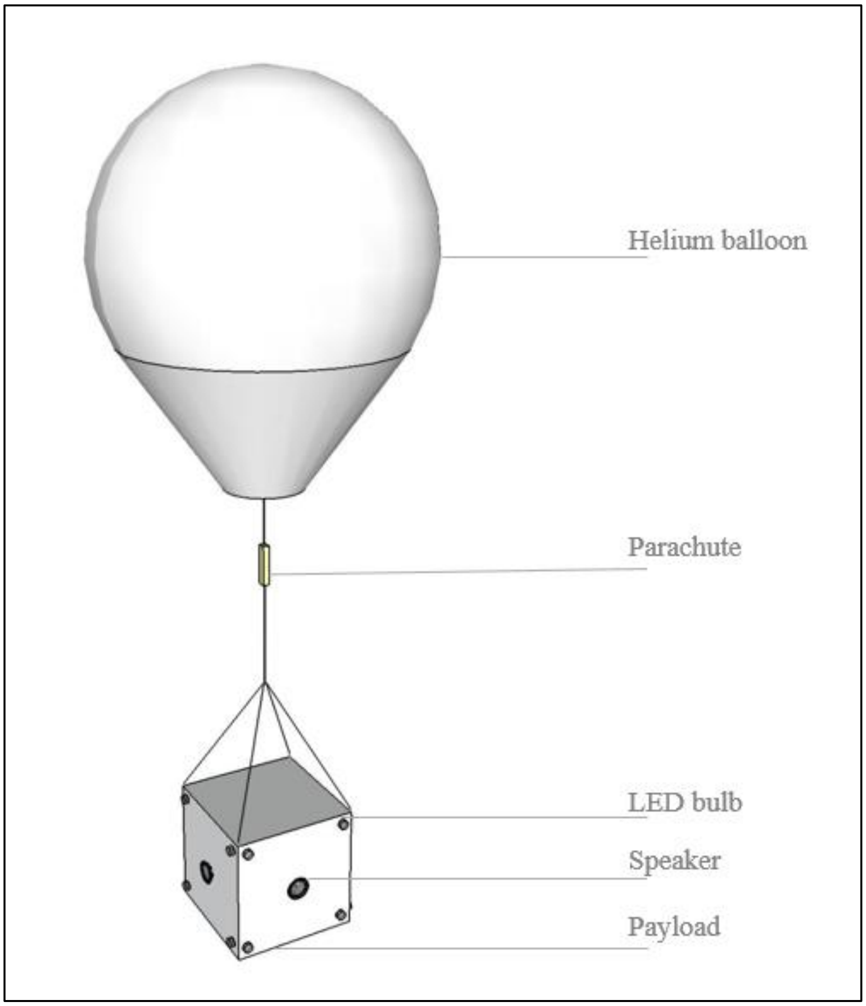

Figure 5: Physical Design of our Radiosonde

3. Design Verification

3.1 Identification Unit

The Identification unit has a functional purpose of being heard and visible from a medium distance away. The was to aid in location of the device once at the given GPS location. Once the Identification unit was constructed we began the following test to verify its functionality. We needed to verify the functionality of the LEDs and the speakers on the identification unit.

We required that the identification unit be heard at 15 meters distance. We tested this by placing the device on a field with no obstructions and walking 15 meters from it. We activated the device and were able to hear the speakers. Thus, we confirmed the functionality of the speakers.

We required that each LED blink with flash 30 times per minute. We verified this functionality by counting the number of flashes in one minute. We counted 30 times per minute and thus verified the functionality of the LEDs.

3.2 GPS and GSM Unit

The GPS and GSM unit had three requirements total. The first requirement was that it must be able to get a GPS location within 15 meters of where the actual device is. We tested this functionality by using the unit to get a GPS location and then measuring the distance between where the device was and where the given location was. We conducted 3 different tests and all tests fell with 15 meters. Figure 6 below shows a screenshot of the obtained location. It is interesting to note that the given GPS location was more accurate than the location given by the phone. Table 2 shows a summary of the errors, in meters, from each trial.

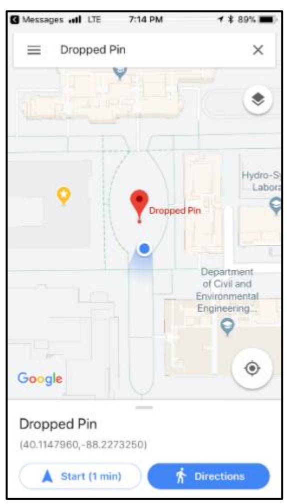

Figure 6: Sample of GPS location feature

Trial #	Error Distance (m)
1	8.2
2	3.5
3	11.7

Table 2: Error summary of the three trials conducted – Distance

The second requirement was that FONA should send GPS coordinates from the module to the user via GSM. We verified that by sending a command to the device and then receiving GPS coordinates. This can be seen in Figure 7 below.

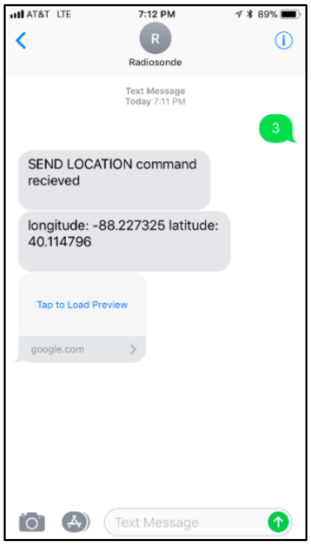

Figure 7: Sample of GPS location sent as a text message

The third requirement was that the unit could trigger LEDs and speakers via a received command. We verified this functionality by sending a command and seeing whether the identification unit activated. It did and thus we verified this functionality as well.

3.3 Sensor Unit

The sensor unit required that each measurement of temperature and pressure be accurate to within a specified error. Furthermore, it required that it take at least on sample every 12 seconds. We noticed that the device took a sample very two to three seconds. Furthermore, we checked the measured temperature and pressure values against local weather data and found that the error fell within our specified value. Table 3 below, shows a summary from each of our trials.

Trial	Error Pressure (kPA)	Error Temperature (^{0}C)
1	0.23	1.2
2	0.17	3.7
3	0.33	1.1

Table 3: Error summary of the three trials conducted – Pressure and Temperature

3.4 Storage Unit

The storage unit required that we store all the data without any data loss. We verified this by specifying that a number of samples be taken and then checking the SD card to see if that number of samples were stored. We measured 10 times and stored the data 10 times, as shown in Figure 8 below. When the SD card was checked we did find 10 entries of data, thus confirming its functionally.

```
0,2018-04-23-13-26-23,99318.75,167.13,20.44
1,2018-04-23-13-26-25,99340.00,166.00,20.44
2,2018-04-23-13-26-28,99350.75,165.13,20.44
3,2018-04-23-13-26-30,99338.75,164.69,20.44
4,2018-04-23-13-26-33,99331.50,166.13,20.44
5,2018-04-23-13-32-38,99343.75,165.63,17.50
6,2018-04-23-13-32-41,99343.25,165.75,17.56
7,2018-04-23-13-32-43,99340.75,165.75,17.56
8,2018-04-23-13-32-46,99343.00,165.50,17.56
9,2018-04-23-13-32-48,99345.50,165.88,17.56
```

Figure 8: Sample of data stored on SD card

3.5 Control Unit

The control unit had three verifications that needed to be meet in order to be functional. While one of the most complicated parts of the project these requirements were easy to verify as they were very high level.

The first requirement was to communicate with the GPS and GSM module. We verified this by having the control unit command the GPS and GSM module for a location and then to send the response to a debugging terminal. This was done successfully and verified the first requirement.

The second requirement was to communicate the storage unit via I2C protocol. We were able to verify this functionality at the same time we verified the storage unit's functionality. This resulted in the figure in section 3.4. Thus, we verified the second requirement.

The third and final requirement was to trigger the LEDs and Speakers. We were able to verify this at the same time we verified the identification unit. A command was sent and the control unit activated the LEDs and Speakers thus verifying the third requirement.

4. Costs

4.1 Parts

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
ATMega2560p	Atmel	12	12	12
microSD card 16 GB	SanDisk	6.95	6.95	6.95
Super bright LEDs	Shenzhen Fuhrer photoelectric co.	6.95	6.95/25 pack	2.22
MCP320B2	Mallory	3.90	3.14	3.14
Custom-printed PCB	N/A	3.22	3.22	3.22
FONA 808 Shield - Mini Cellular GSM + GPS	Adafruit	50	50	50
MicroSD card breakout board	Adafruit	9.88	9.88	9.88
Quad band antenna	Adafruit	2.95	2.95	2.95
Misc.	N/A	15	15	15
Total				$ 105.36

Table 4: Cost of Parts

4.2 Labor

Total Salary = ($/hour) x 2.5 x hours to complete

	Hourly Rate	Hours per week	Weeks to complete	Total Salary
Khushboo Jain	$30/hour	40	15	$45,000
Lake Boddicker	$30/hour	40	15	$45,000
Raunak Barnwal	$30/hour	40	15	$45,000
Total				$ 135,000

Table 5: Cost of Labor

Total cost of project = Total Labor + Total Parts = $135,000 + $105.33 = **$ 135,105.36**

5. Conclusion

5.1 Accomplishments

Our device is a fully functional, customizable and low-cost radiosonde. We were able to test the radiosonde on a tethered launch to generate a successful sounding analysis. The radiosonde features a programmable barometer, thermistor and altimeter for this launch interfaced with the control unit that features the ATMega2560 microcontroller. In addition to this, we were able to change and control states of the radiosonde prior to and after the launch, successfully load the data onto an on-board micro-SD card. The radiosonde was controlled through SMS on a cellphone. Figures 10 and 11 bellow depict the control commands the instrument is currently capable of receiving. Battery status and error upon entering incorrect command numbers are not shown.

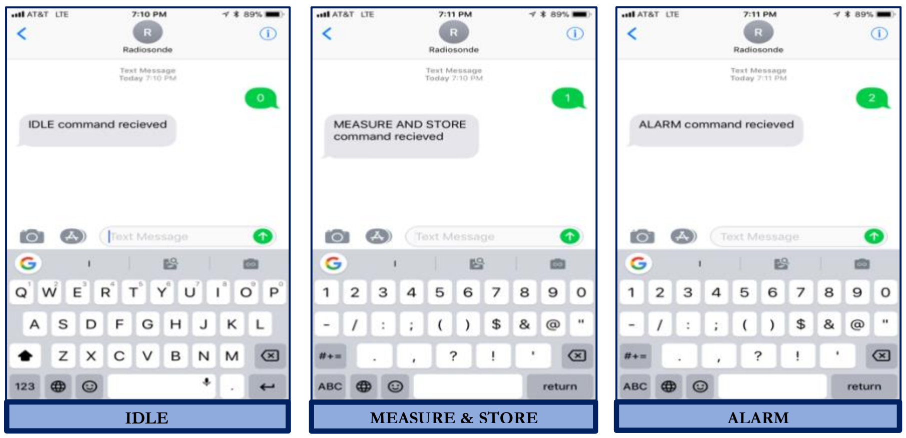

Figure 9: Idle (0), Measure & Store (1), ALARM (2) commands

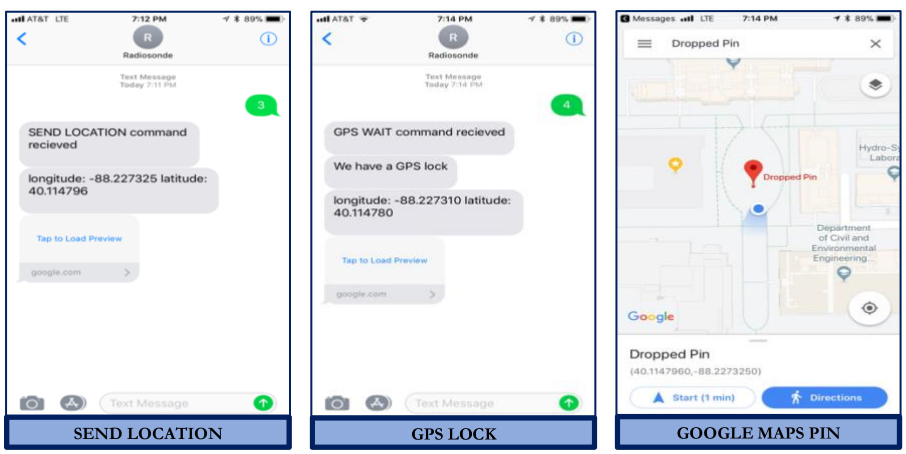

Figure 10: Location (3), GPS (4) and location pin

In addition to this, a graph depicting the pressure changes on a sample tethered launch is shown in Chart 1 below. The pressure falls as the balloon ascends and begins to increase again as the tether is pulled back down.

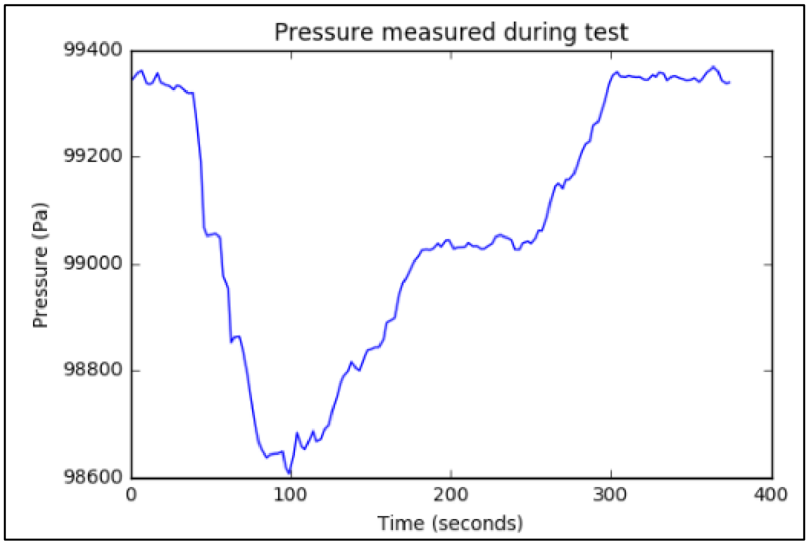

Chart 1: Sample graph of Pressure decrease as HAB ascends and is tethered down.

5.2 Uncertainties

There exist uncertainties regarding the viability of a retrievable radiosonde on a large, national launch scale. The majority of which is in regard to the lack of data available on the drop zone of high altitude balloons of this type. The current launch network for the radiosonde is depicted below. Each launched device is subject to horizontal displacement due to high windspeeds at the jet stream level.

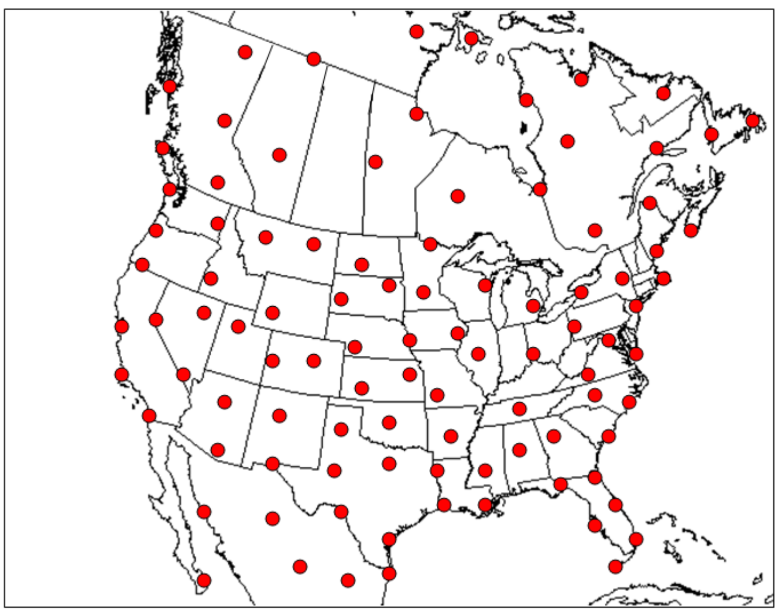

Figure 11: Radiosonde Launch-sites across the US [1]

While this retrievable radiosonde serves as an excellent reusable device for short-range launches, there is no data collected or made available on how far from launch sites these devices typically land when they are used for forecast purposes and may reach altitudes that experience high horizontal wind drift at the jet stream levels. A certain percentage of the radiosondes launched for weather forecast purposes may also be irretrievable due to aqueous drop zones. For example, if the radiosonde drops down into a water body or another irretrievable region. This information is current unavailable as little research has been done in this area. Traditional radiosondes are typically disposed-off after single use. Therefore, the viability of these retrievable radiosondes on a large, national-scale is subject to uncertainty.

5.3 Ethical considerations

Our project is by and large benign, however there are some safety concerns related to releasing a high-altitude balloon. Such an object can interfere or damage aircraft that happen to be in the same area as the weather balloon. There exist a number of regulations that need to be followed. This includes a Notice to Airmen (NOTAM) [2] that needs to be filed before launching the device with a helium balloon.

For the purposes of our verification, the device may be tethered with string (nylon) and stores all observation data on an internal SD card module, therefore the device poses little threat and is a non-aerial, tethered launch device. If the radiosonde is launched untethered, safety and precaution is advised to developers for aerial devices. In addition to this, if the radiosonde transmits at radio frequency, additional care must be taken to abide by the FCC rules on power and RF transmission [3].

Our design requires the use of a lithium ion battery. Leakage or venting of Li-ion cells will release flammable vapors. Therefore, extra care and precaution is taken while handling as well as designing the implementation of these batteries.

This project is built for the purposes of scientific research and use. We abide by all IEEE code of ethics in completing this project [4].

5.4 Future work

The results of this project open new doors for atmospheric and research scientists. Future work on this project may encompass testing new sensors. CO_2 sensors and $PM_{2.5}$ (Particulate Matter) sensors may be used to test the radiosonde's viability as a pollution tracker in the future. In addition to this since the radiosonde's is fully customizable and programmable, other experiments may be carried out. For example, using GoPro cameras on High Altitude Balloons is popular amongst hobbyists. This may be especially useful during special atmospheric events to study the effects of atmospheric phenomenon on the troposphere. For example, the impact of temperature differences during total solar eclipse.

In addition to this, to properly make this device functional for organizations such as the National Weather Service (NWS), a network system needs to be set up. The horizontal drift due to the jet stream and winds in the upper troposphere displace the radiosonde. The average displacement needs to be studied as well as measures must be taken to analyze expected drop zones for the instrument. The local NWS office may then retrieve and reuse a radiosonde launched from a different zone.

References

[1] *A World of Weather: Fundamentals of Meteorology,* Department of Meteorology at Penn State University, Pennsylvania 2010.

[2] "Prohibitions, Restrictions and Notices." *FAA seal*, 14 Feb. 2018, www.faa.gov/air_traffic/publications/us_restrictions/

[3] "Rules & Regulations for Title 47." *Federal Communications Commission*, 21 Dec. 2017, www.fcc.gov/wireless/bureau-divisions/technologies-systems-and-innovation-division/rules-regulations-title-47.

[4] "IEEE Code of Ethics." *IEEE* - IEEE Code of Ethics, www.ieee.org/about/corporate/governance/p7-8.html.

Appendix A Requirement and Verification Table

Control Unit (ATmega Microcontroller)		
Verification Status (Y or N)	**Requirements**	**Verification**
Y	Communicates with the Tracking Unit (GPS+GSM unit) via UART module	The microcontroller will read GPS data from the Tracking Unit and display it on the computer. GPS signal must be above -100 dBm.
Y	Communicates with the Storage Unit (SD Card) via I2C protocol	Write dummy values onto the SD card using the microcontroller and check the number of data points and accuracy using an external SD card reader.
Y	The microcontroller should trigger the LEDs and Speakers	LED lights must start flashing and speakers must turn ON

Tracking Unit (GPS+GSM unit)		
Verification Status (Y or N)	**Requirements**	**Verification**
Y	The unit should indicate location to an accuracy of within 15 ± 2.5 meters measured as a radial-distance from the instrument.	Simulate a tracking test by randomly placing our radiosonde at known locations and measure the distance between our GPS coordinates and its actual location and accuracy in readings. 5 tests will be conducted. Signal power must be higher than -100 dBm.
Y	The unit should send GPS coordinates from the module to the user via the GSM module	Verify that the received data values are valid and accurate GPS coordinates, when power level is higher than -100 dBm.
Y	The unit should receive the command to trigger LEDs and speakers	The microcontroller will indicate the receipt of trigger signal, when power level > -100 dBm.

Power Unit		
Verification	**Requirements**	**Verification**

Status (Y or N)		
Y	The power unit must provide a voltage of 5.0 ± 0.5 V dc to the Control Unit	Use voltage probe and Oscilloscope to view the ripple across the voltage supplied
Y	The power unit must provide a voltage of 5.0 ± 0.5 V dc to the Sensor Unit	Use voltage probe and Oscilloscope to view the ripple across the voltage supplied
Y	The power unit must provide a voltage of 5.0 ± 0.5 V dc to the Storage Unit	Use voltage probe and Oscilloscope to view the ripple across the voltage supplied
Y	The power unit must provide a voltage of 3.7 ± 0.6 V dc to the Tracking Unit	Use voltage probe and Oscilloscope to view the ripple across the voltage supplied

Sensor Unit		
Verification Status (Y or N)	**Requirements**	**Verification**
Temperature Sensor		
Y	The temperature sensor should accurately read temperature to ± 4℃	Verify that data is within accuracy as compared to local temperature readings for Champaign, IL, provided by Weather.com.
Y	The sensors should collect temperature readings at a rate of 5 samples/minute	Analysis of total flight time and the number of samples collected should be in accordance with the data sampling rate.
Pressure Sensor		
Y	The pressure sensor should accurately read pressure to ± 10 millibar	Verify that data is within accuracy as compared to local pressure readings, surface readings from a barometer.
Y	The sensors should collect pressure readings at a rate of 5 samples/minute	Analysis of total flight time and the number of samples collected should be in accordance with the data sampling rate.

Storage Unit (SD Card)		
Verification Status (Y or N)	**Requirements**	**Verification**
Y	Store all the data from the sensors without any data loss	Cross check the number of data points collected with the sampling rate of each sensor and the overall flight time.

Identification Unit		
Verification Status (Y or N)	**Requirements**	**Verification**
Speakers		
Y	The speaker on the radiosonde should be audible by the human ear at the location provided by the GPS module.	Test the radiosonde at varying distances, between 0-15 meters from the GPS coordinates provided, for audibility levels of the sound emitted from the speaker by a simple "audible" or "inaudible" test.
Y	Each of the four speakers should be programmed to beep/tweet at a 0.5 Hz frequency to be identifiable by the human ear.	30 ± 5 beeps per minute, from each speaker, can be counted to check for the frequency of the sound output.
LED Lights		
Y	Each of the sixteen LEDs should be programmed to flash at a 0.5 Hz frequency to be identifiable by the human eye.	30 ± 5 blinks per minute, on each LED, can be counted to check for the frequency of the blinking.